



ANALYSIS OF WHEEL HUBS

Student Car

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ABSTRACT

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JESÚS FCO. RINCÓN GARCÍA:
Analysis of Wheel Hubs

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The aim of this thesis work is to do the study and analysis of Student Car wheel hubs.

The first part is a briefing of the “StudentCar” competition and a short explanation of the problem. Also it talks about the information and files that the team have about their hubs.

After that, the document has short information about the basics knowledge of *Strength of Materials* necessary for to do the analysis in hubs and information about the material used by the team (Aluminum Alloy 7075-T6).

But the context of this thesis talks about how to do a basic failure analysis.
And how to do a more specific analysis with ANSYS software using the ANSYS results in Miner's rule (kind of failure analysis for a cumulative damage).

Finally the document includes the results of this analysis; the possible changes that can do better pieces; also it includes short explanation who talks about the possible mistakes in analysis results.

At the end, this thesis work talks about the final conclusions and the comments of the author.

CONTENTS

1	INTRODUCTION	7
1.1	Cooperation with Formula Student Team	8
1.2	Brief Introduction to the Behavior of the Hub	8
2	PROBLEM	9
2.1	Information Provided by the Team	9
2.1.1	Basic Information about the Car and the Circuits	9
2.1.2	Information Obtained in Tests (Aerodynamic Forces)	11
2.1.3	Design of Suspension (CATIA)	12
3	KNOWLEDGE AND INFORMATION NECESSARY	15
3.1	Strength of Materials Theory	15
3.1.1	Type of Loadings: Normal Force (Axial Force), Shear Force, Bending Moment and Torsion (Torque)	15
3.2	Information about our Material: Aluminum Alloy 7075-T6	16
3.2.1	Strain Control Fatigue (Graphs and Equations)	17
3.2.2	Material Properties (Aluminum Alloy 7075-T6)	20
3.3	Introduction to Failure Analysis	21
3.3.1	Failure Analysis (Miner's Rule)	21
4	SOFTWARES FOR DESIGN AND ANALYSIS 3D	23
4.1	CATIA V5	23
4.2	ANSYS Workbench 14.5	23
5	HUBS OF THE WHEEL	25
5.1	Front Wheel Hub	25
5.1.1	Initial Design (CATIA)	26
5.1.2	Mathematical Calculations	29
5.2	Rear Wheel Hub	32
5.2.1	Initial Design (CATIA)	33
5.2.2	Mathematical Calculations	35
5.3	FATIGUE ANALYSIS	38
5.3.1	Basic Calculation	38
5.3.2	Calculation with ANSYS Workbench	44
6	RESULTS	47
6.1	Fatigue Analysis on Original Pieces (ANSYS)	47
6.1.1	Front Hub	47
6.1.2	Rear Hub	50
6.2	Analysis of Fatigue Results (ANSYS)	52
6.2.1	Front Hub	52

6.2.2 Rear Hub	53
7 PROPOSED CHANGES IN HUBS	54
7.1 Proposed Changes with Limited Modification Conditions.....	54
7.2 Proposed Changes without any Limited Modification Conditions.....	54
8 CONCLUSIONS AND MY COMMENTS	56
REFERENCES.....	58
APPENDICES	59
Appendix 1. Forces in One Lap.....	59
Appendix 2. Miner's Rule Front Hub	63
Appendix 3. Miner's Rule Front Hub, Infinite Life = 0.....	67
Appendix 4. Miner's Rule Rear Hub.....	71
Appendix 5. Miner's Rule Rear Hub, Infinite Life = 0.....	75

GLOSSARY or ABBREVIATIONS AND TERMS (choose one or other)

TAMK	Tampere University of Applied Sciences
cr	credit
CATIA	CAD software
ANSYS	CAE software
N	Normal Force in axis X
T _y	Shear Force in axis Y
T _z	Shear Force in axis Z
M _y	Bending Moment in axis Y
M _z	Bending Moment in axis Z
M _x	Torsion or Torque (axis X)
Al	Aluminum
S	Smooth specimens
N	Notched specimens
E	Slope
σ'_f	fatigue strength ductility coefficient
ϵ'_f	fatigue ductility coefficient
N _f	number of cycles to failure
c	fatigue ductility exponent
b	fatigue strength exponent
Si	Spectrum
n _i	cycles
N _i	number of cycles to failure of a constant stress reversal
C=D _{lab}	experimental variable
K _a	Force generate by the friction of the wheels in the curves
K _d	Normal force generate in every time by the weight of the car
K _t	Force generate by the friction of the wheels when the car braking
F _{ay}	Force reaction in point A and axis Y
F _{az}	Force reaction in point A and axis Z
F _{by}	Force reaction in point B and axis Y
F _{bz}	Force reaction in point B and axis Z
F _{bx}	Force reaction in point B and axis X

μ	Tire friction coefficient
G	Gravity force
m_l	Total weight
F_{ac}	Acceleration force
F_{dec}	Deceleration force
r_h	Centre of gravity height
r_b	Centre of gravity distance to rear wheel
r_a	Centre of gravity distance to front wheel
$N_{e.dyn}$	Dynamic weight force in front wheels
$N_{t.dyn}$	Dynamic weight force in rear wheels
$r_{.as}$	wide between center of gravity and wheel
$N_{s1.dyn}$	Dynamic weight force in left wheels (side forces in corners)
$N_{s2.dyn}$	Dynamic weight force in right wheels 2 (side forces in corners)
RA	Distance between point R and point A
RC	Distance between point R and point C
RB	Distance between point R and point B
AB	Distance between point A and point B
A	Area of section
I_{zz}	Inertia of section in axis Z
I_{yy}	Inertia of section in axis Y
R	External radius in section
r	Internal radius in section
σ_{eq}	Equivalent stress in section
σ_{max}	Equivalent maximum stress in section
σ_{min}	Equivalent minimum stress in section
σ_u	Tensile Ultimate Strength
$\sigma_{lim}=\sigma_y$	Compressive Yield Strength
EL	Endurance limit
K_a	Surface Condition Factor
K_b	Size Factor
K_c	Load Factor
K_d	Temperature Factor
K_e	Reliability Factor
K_f	Miscellaneous Factor

1 INTRODUCTION

This thesis is anchored in the context of building a car for the international competition 'Formula Student' whose goal is to give to the students from different universities the opportunity to learn and know more about the world of competition, because this uses the engineer knowledge.

Moved for their passion for the vehicles, this group of students has ventured into the intricacies of this machine and learn a little more about his structure, performance and tuning.

Formula Student is a challenge among university teams from European universities and the rest of the world.

It consists in design and develops a prototype racing car.

It will race in different European circuits with the consequent evaluation in a championship.

The competition itself is a challenge for students, where such a specified period of time, they have to demonstrate and prove their ability for create and innovate, and the ability to directly apply their skills as engineers compared to other teams from universities around the world.

The aim of the project is redesign the wheel hubs which will then be used in the Formula Student car that representing the TAMK University of Tampere.

To optimize it is necessary to do different analysis and simulation studies.

To carry out the objective of redesign hubs of a car, first step is modeling the piece with the damping system; add in it the movement restrictions and the most similar loads or forces which the piece will be impacted. Thereafter, the model is analyzed.

If necessary, you can change the size of the model, but this has to fit into the design of the rest of the vehicle and support the loads.

Finally, the final model is analyzed.

Data obtained in tests for the designs and redesigns of the vehicle were used.

With the information, the piece is simulated in critical situations, the behavior is observed and the features are improved (agility, flexibility, cost, etc.).

Finally, the piece is mounted in the car so is possible to create a comprehensive and real vision of it.

This thesis is based on the study and redesign of one of the basic part of a car: the hubs of the wheels.

To carry out this project, the benefits of 3D simulation software called CATIA, and simulation software called ANSYS (finite element) took advantage.

Today it isn't infeasible to build a similar machine without the help of a specialist to model and analyze the behavior of each of the parts of the software.

1.1 Cooperation with Formula Student Team

I would like to thanks to the TAMK's team for give me the opportunity of help in that project, because I know which it is good opportunity for me for learn more about the world of design in a competition.

That thesis is a short part of all work involved the design of a FormulaStudent car.

I want help TAMK's team with my thesis and wish to the team luck in this competition

1.2 Brief Introduction to the Behavior of the Hub

In order to delve into the real subject of study of this project is necessary to introduce brief information about the operation and behavior of the wheel hub.

The hubs or axes support machine elements at rest or rotating, as in our case the wheels. Also the hubs or axes withstand axial forces, cutting forces, bending's and torsional moments.

The alternative bending of the rotary axes brings the danger of fatigue failure in every transition section, every change of section, every groove, holes, etc.

The stress spikes can be eliminated by taking various precautions during design.

Finally, it is possible to prevent axial displacement centers or axes with lateral stop on the bearing, snap rings or circlips.

2 PROBLEM

The problem in this part of the work (the car design) is to find the optimal design for hubs. The team only did basics calculus for do the first design in the hubs, but they want know more about the real work of it.

In the first point, the team want know when the current hubs will break, because that pieces need support a number of cycles and they wouldn't like that pieces break in the middle of the race.

Known if parts endure or not endure this number of cycles, the parts are manufactured adapted to the required needs.

With some calculus and with CATIA and ANSYS, it's possible to solve this problem.

2.1 Information Provided by the Team

The team couldn't give more information about the car because that is now in developing of the design process and them don't have more information.

But they had basic and necessary information for to do the design of hubs.

The information is dividing in different sub-points:

- Basic information about the car properties and the circuits
- Information obtained in tests (Aerodynamic forces)
- Design of suspension by CATIA

2.1.1 Basic Information about the Car and the Circuits

The team knew some proprieties about the car design. With that information and the aerodynamic information, is possible to calculate the loads in hubs.

A resume of the car information is in the next data table (TABLE 1):

TABLE 1. Information about the car.

Name	Unit	Value
Car weight	Kg	190
Driver weight	Kg	80
Tire friction coefficient (we assumed it to be constant)	-	1,6
Wheelbase	mm	1600
Centre of gravity height	mm	340
Centre of gravity distance to front wheel	mm	912
Centre of gravity distance to rear wheel	mm	688
Dynamic weight distribution	-	1:1
Wheel diameter	mm	457,2
Distance between wheels on the same axle	mm	1260
Distance from the front wheel to the first bearing	mm	58,5
Distance between front bearings	mm	35
Distance from the rear wheel to the first bearing	mm	15
Distance between rear bearings	mm	38

Also, the team knew the distance that the piece has to endure:

Five circuits similar to FS Germany Circuit (PICTURE 1) and one circuit more for tests (Toijalan Circuit).

The FS Germany Circuit (1 km/lap) include:

Endurance	-	22	laps
Autocross	-	4	laps
Skidpad	-	2	laps
Test	-	3	laps
TOTAL	-	31(x5)	laps

The Toijalan Circuit (0,8 km/lap) include:

Test season	-	700	laps
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Is important know the most fast lap in FS Germany because is necessary to use this time for design. The fast lap in FS Germany is around 73 seconds.

2.1.2 Information Obtained in Tests (Aerodynamic Forces)

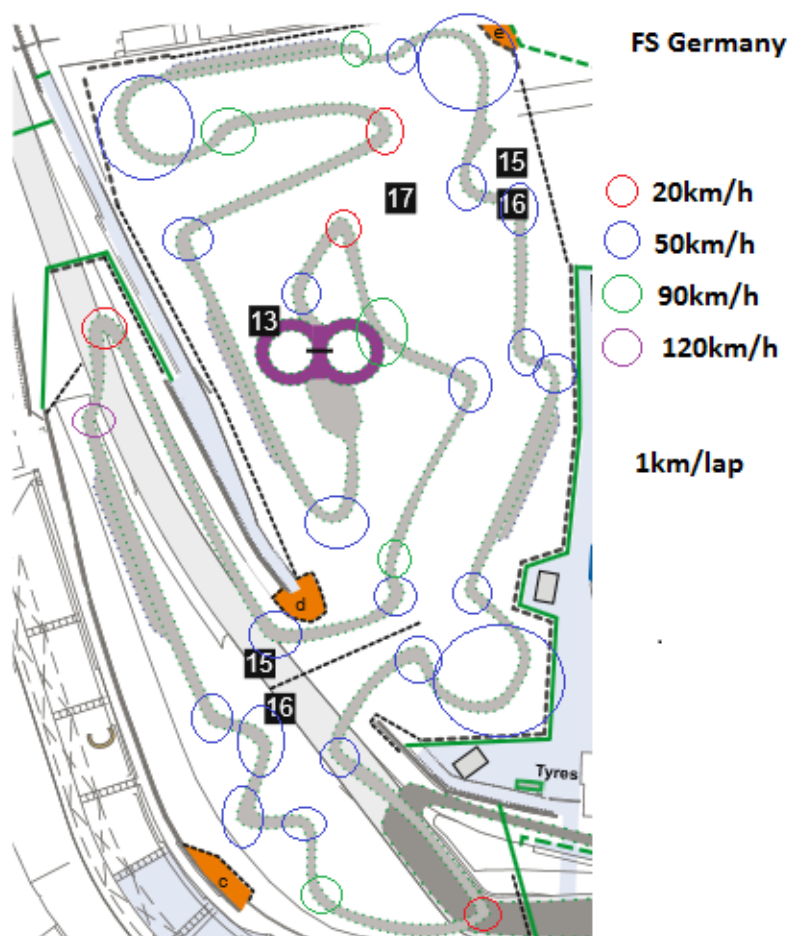
The team had basic information about the downforces obtained in one test (FIGURE 1, FIGURE 2).

That document is a data table with the downforces for a front wing and for a rear wing in different speeds (20Km/h, 50Km/h, 90Km/h and 120 Km/h).

With that data table is possible to design two plots with excel and to obtain the functions with a trendline.

With the functions we can obtain the approximate load for an every speed.

Also the top speed of the car is 120 Km/h.



PICTURE 1. Information of speeds in FS Germany circuit. (Formula Team 2014).

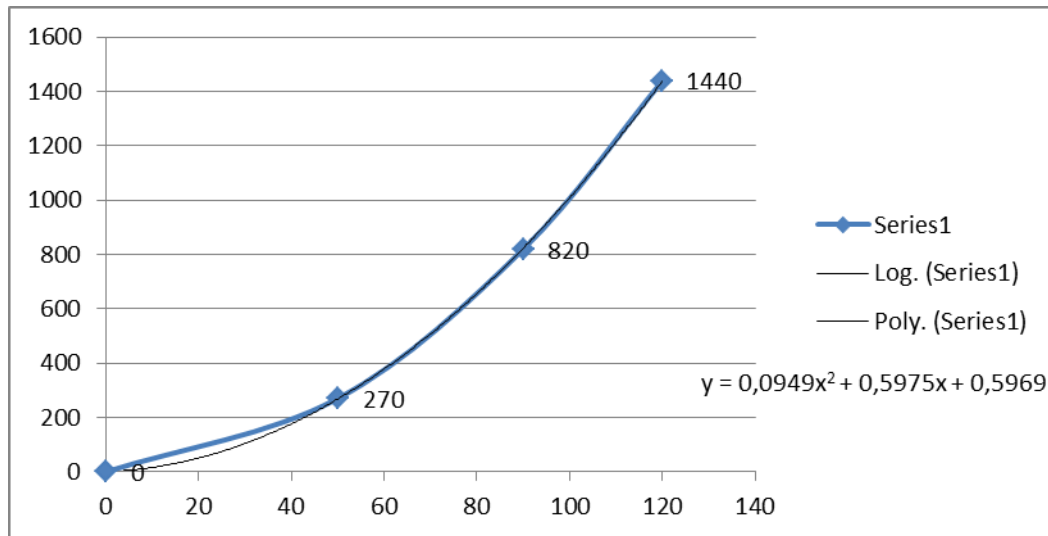


FIGURE 1. Downforce in the front wing. X axis is speed (Km/h), Y axis is force (N)

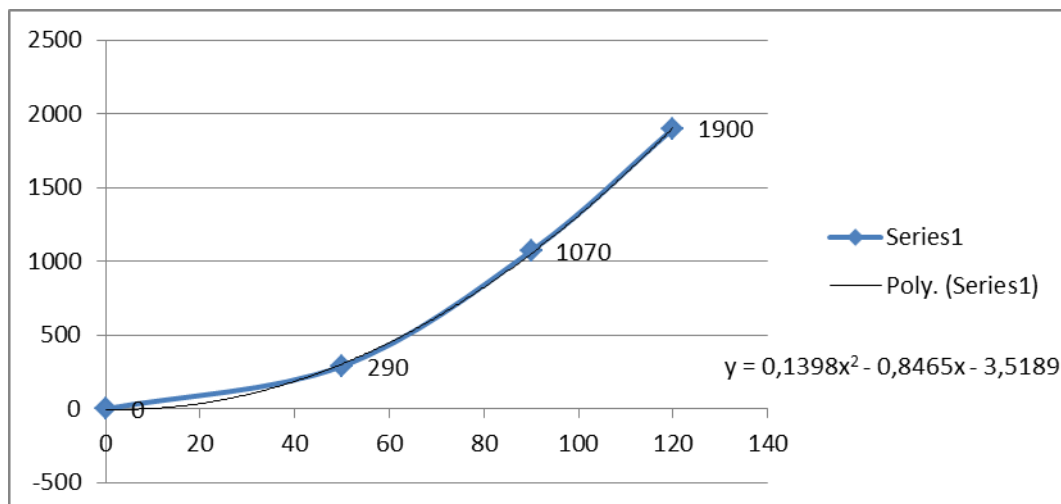
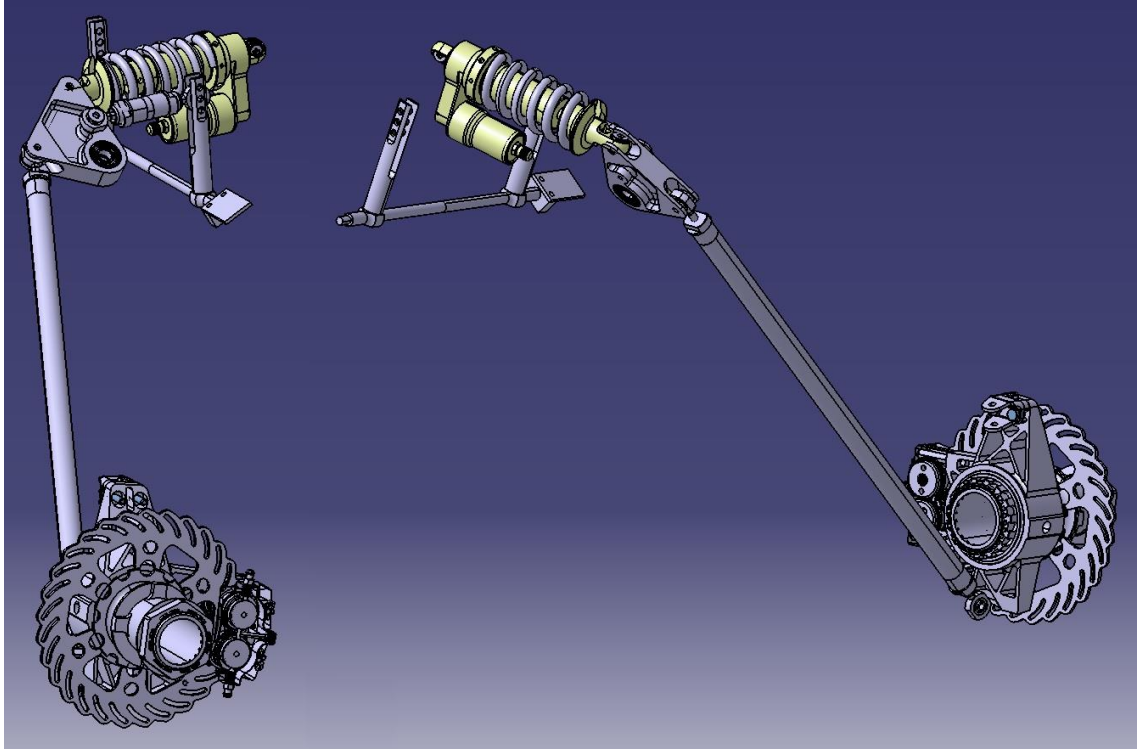


FIGURE 2. Downforce in the rear wing. X axis is speed (Km/h), Y axis is force (N)

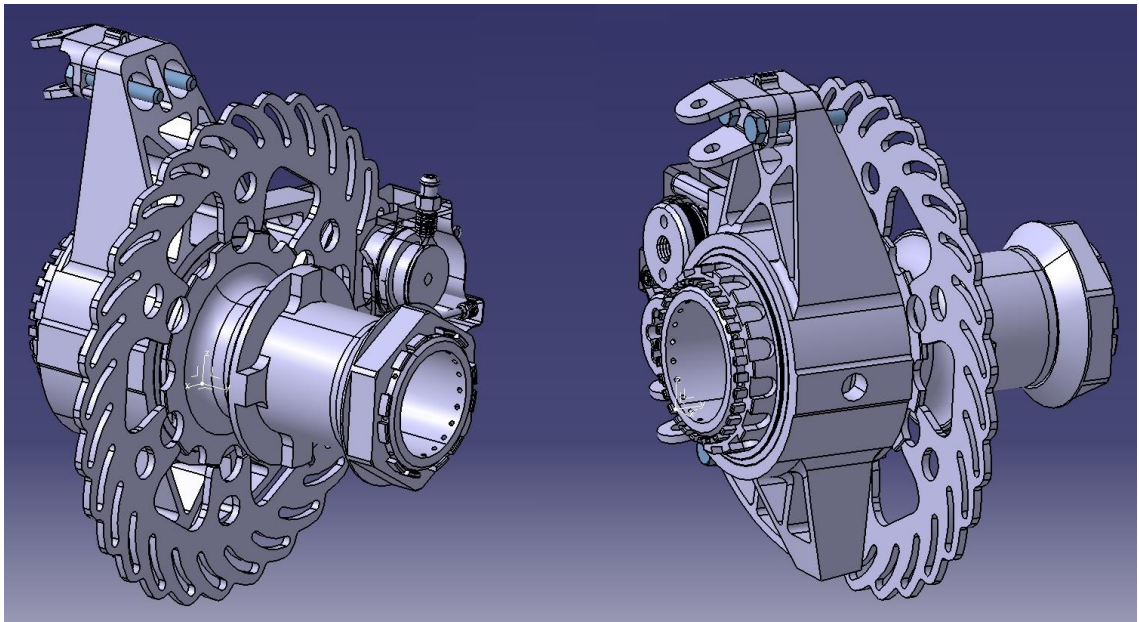
2.1.3 Design of Suspension (CATIA)

Finally, the last information which the team had is a CATIA file with the basic design of the suspension that they are using now (PICTURE 2, 3, 4 and 5).

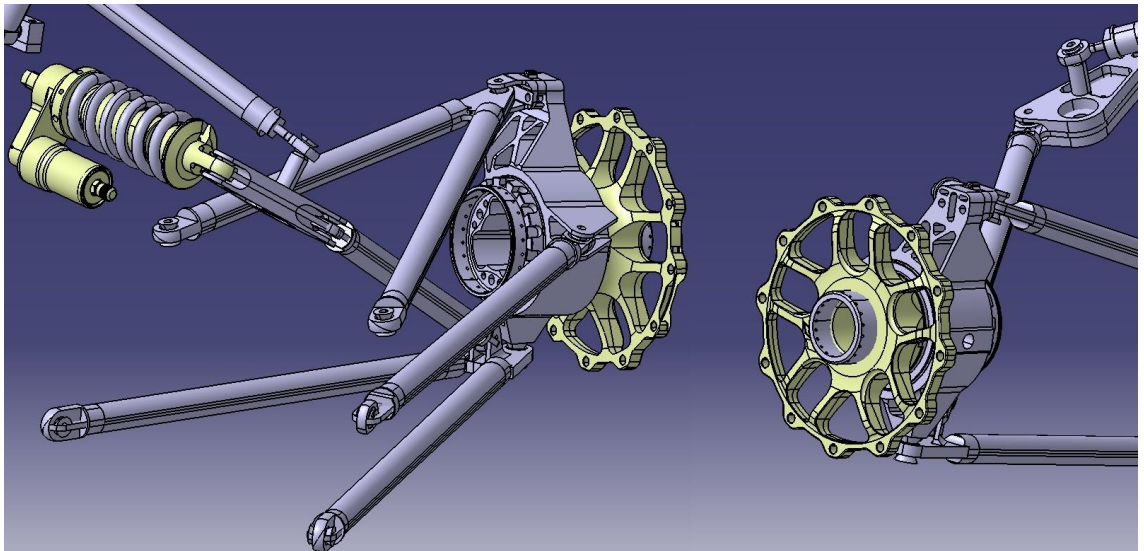
From those information is possible to do a math calculus to get the basic strength and stress in the hubs or is possible to do different analysis with ANSYS and to see the supposed real behavior when pieces work in a fatigue cycle.



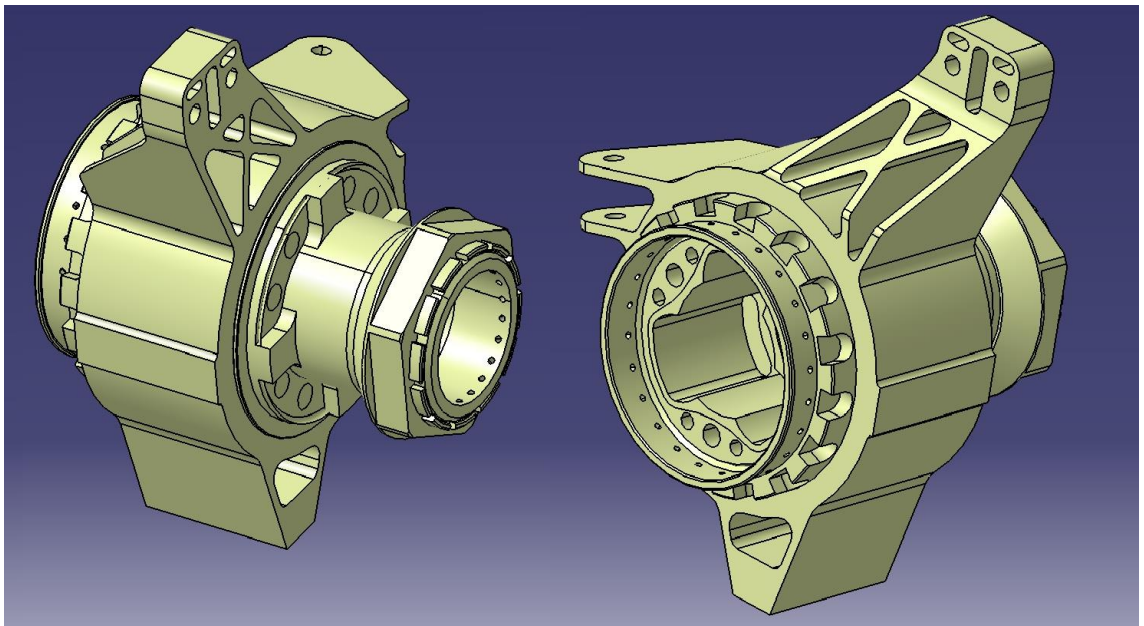
PICTURE 2. Front Suspension.(Formula Team 2014).



PICTURE 3. Front Suspension (Detail). (Formula Team 2014).



PICTURE 4. Rear Suspension. (Formula Team 2014).



PICTURE 5. Rear Suspension (Detail). (Formula Team 2014).

3 KNOWLEDGE AND INFORMATION NECESSARY

Before start with the resolution by mathematical calculus and before ANSYS Workbench it's necessary to have some basic knowledge about the next things:

- Strength of Materials Theory
- Information about out material (Aluminum Alloy 7075-T6)
- Failure Analysis by Miner's rule

3.1 Strength of Materials Theory

Strength of Materials, also referred to as Mechanics of Materials, looks at the behavior of materials when forces are applied to them. These forces include different types of stresses upon and within the material in all different directions, and the strain that is experienced in the material due to those forces.

Studying the reactions of a material usually begins with looking at the static forces on and within the material to determine all of the forces affecting it.

Once this examination is complete, we can find the reactions of the material.

It's important to know how a material behaves because we want redesign pieces.

3.1.1 Type of Loadings: Normal Force (Axial Force), Shear Force, Bending Moment and Torsion (Torque)

1- Axial loading - The applied forces are collinear with the longitudinal axis of the member. The forces cause the member to either stretch or shorten.

This kind of loads generates Normal Forces (N).

2- Transverse loading - Forces applied perpendicular to the longitudinal axis of a member. Transverse loading causes the member to bend and deflect from its original position, with internal tensile and compressive strains accompanying the change in curvature of the member.

Transverse loading also induces shear forces that cause shear deformation of the material and increase the transverse deflection of the member.

This kind of loads generates Shear Forces (T_y , T_z) and Bending Moments (M_y , M_z).

3- Torsional loading - Twisting action caused by a pair of externally applied equal and oppositely directed force couples acting on parallel planes or by a single external couple applied to a member that has one end fixed against rotation.

This kind of loads generates Torsion or Torque (M_x).

3.2 Information about our Material: Aluminum Alloy 7075-T6

Aluminum alloy 7075 (FIGURE 3) is an aluminum alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys.

Its relatively high cost limits its use to applications where cheaper alloys are not suitable.

7075 aluminum alloy's composition roughly includes:

5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper, and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals.

It is produced in many tempers, some of which are 7075-0, 7075-T6, 7075-T651.

3.2.1 Strain Control Fatigue (Graphs and Equations)

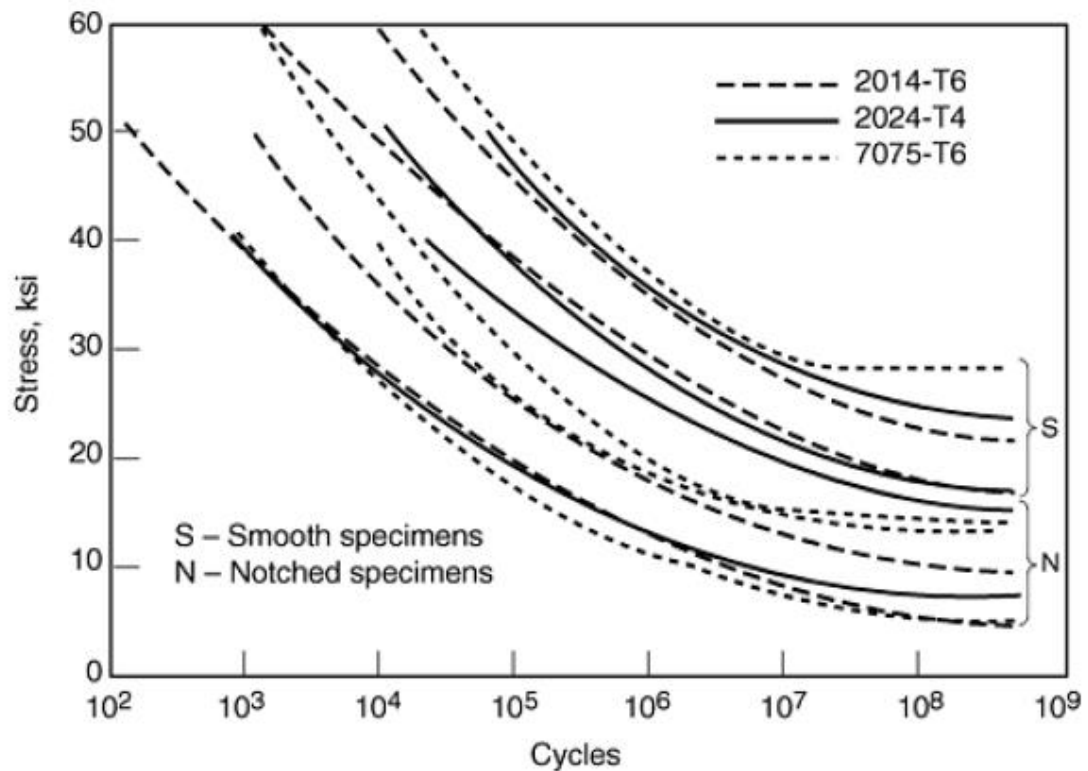


FIGURE 3. Comparison of fatigue strength bands for 2014-T6, 2024-T4, and 7075-T6 Aluminium Alloys for rotating-beam tests. Source: R.Templin, F.Howell, and E.Hartmann, “Effect of Grain-Direction on Fatigue Properties of Aluminium Alloys”, ALCOA, 1950

In general, strain-life fatigue is based on the division of cyclic stress-strain response into plastic and elastic components (FIGURE. 4a), where the relation between stress and strain depends on the strength-ductility properties of the material (FIGURE 4b) and also the cyclic hardening or softening of the material. For most metals, stress-strain hysteresis behavior (FIGURE 4) is not constant, as cyclic softening or hardening can occur by reversed loading and cyclic straining.

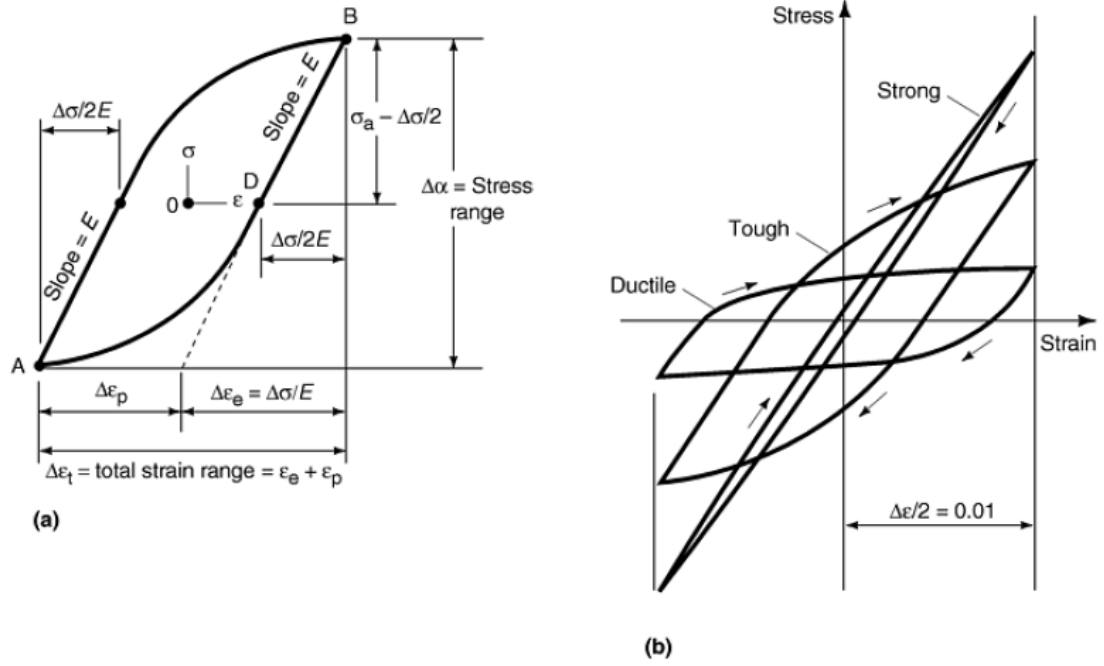


FIGURE 4. Stress-Strain Hysteresis Loop under cyclic loading. (A) Elastic and Plastic Strain Range. (B) Hysteresis Loops showing idealized stress-strain behavior for different types of materials.

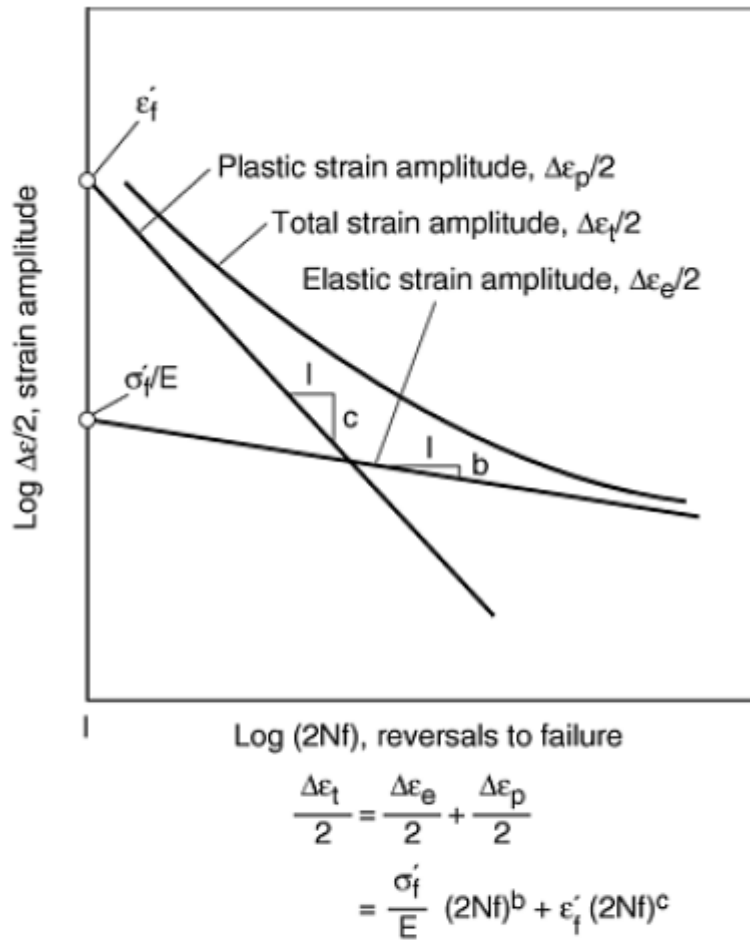
With strain-life fatigue, the elastic and plastic components may be separated and plotted on a strain life curve (FIGURE 5). A plot on logarithmic coordinates of the plastic portion of the strain amplitude (half the plastic strain range) versus the fatigue life often yields a straight line, described by the equation

$$\frac{\Delta\epsilon_p}{2} = \epsilon'_f (2N_f)^c \quad (\text{EQ 3})$$

Where “ ϵ'_f ” is the fatigue ductility coefficient, c is the fatigue ductility exponent, and N_f is the number of cycles to failure ($2N_f$ is the number of load reversals). In contrast, elastic strains influence fatigue behavior under long-life conditions, where a stress-based analysis of fatigue is charted by plotting stress amplitude (half the stress range) versus fatigue life on logarithmic coordinates. The result is a straight line having the equation

$$\frac{\Delta\sigma}{2} = \sigma'_f (2N_f)^b \quad (\text{EQ 4})$$

Where “ σ'_f ” is the fatigue strength coefficient and b is the fatigue strength exponent.



Where: σ'_f = Fatigue strength ductility coefficient
 ϵ'_f = Fatigue ductility coefficient
 b = Fatigue strength exponent
 c = Fatigue ductility exponent

FIGURE 5, Strain Control Fatigue Life as a function of elastic-, plastic-, and total-strain amplitude. ASM Handbook, Volume 19

The elastic strain range is obtained by dividing Eq 4 by Young's modulus E :

$$\frac{\Delta \epsilon_e}{2} = \frac{\sigma'_f}{E} (2N_f)^b \quad (\text{EQ 5})$$

The total strain range is the sum of the elastic and plastic components, obtained by adding Eq 3 and 5 (FIGURE 5):

$$\frac{\Delta \epsilon}{2} = \epsilon'_f (2N_f)^c - \frac{\sigma'_f}{E} (2N_f)^b$$












(EQ 6)

For low-cycle fatigue conditions (frequently fewer than about 1000 cycles to failure), the first term of Eq 6 is much larger than the second; thus, analysis and design under such conditions must use the strain-based approach. For long-life fatigue conditions (frequently more than about 10,000 cycles to failure), the second term dominates, and the fatigue behavior is adequately described by Eq 4. Thus, it becomes possible to use Eq 4 in stress-based analysis and design.

3.2.2 Material Properties (Aluminum Alloy 7075-T6)

After this short background, we used in ANSYS software the next information about the material (TABLE 2 and FIGURE 6).

TABLE 2. Material Properties. ANSYS Workbench 14.5.

Property	Value	Unit
 Density	2,81	g cm ⁻³
 Isotropic Secant Coefficient of Thermal Expansion		
 Coefficient of Thermal Expansion	2,3E-05	C ⁻¹
 Reference Temperature	22	C
 Isotropic Elasticity		
Derive from	Young's Mod...	
Young's Modulus	72000	MPa
Poisson's Ratio	0,33	
Bulk Modulus	7,0588E+10	Pa
Shear Modulus	2,7068E+10	Pa
 Alternating Stress R-Ratio	Tabular	
Interpolation	Semi-Log	
Scale	1	
Offset	0	Pa
 Strain-Life Parameters		
Display Curve Type	Strain-Life	
Strength Coefficient	8,7632E+08	Pa
Strength Exponent	-0,0751	
Ductility Coefficient	0,4664	
Ductility Exponent	-0,7779	
Cyclic Strength Coefficient	9,432E+08	Pa
Cyclic Strain Hardening Exponent	0,0966	
 Tensile Yield Strength	421	MPa
 Compressive Yield Strength	503	MPa
 Tensile Ultimate Strength	572	MPa
 Compressive Ultimate Strength	0	MPa

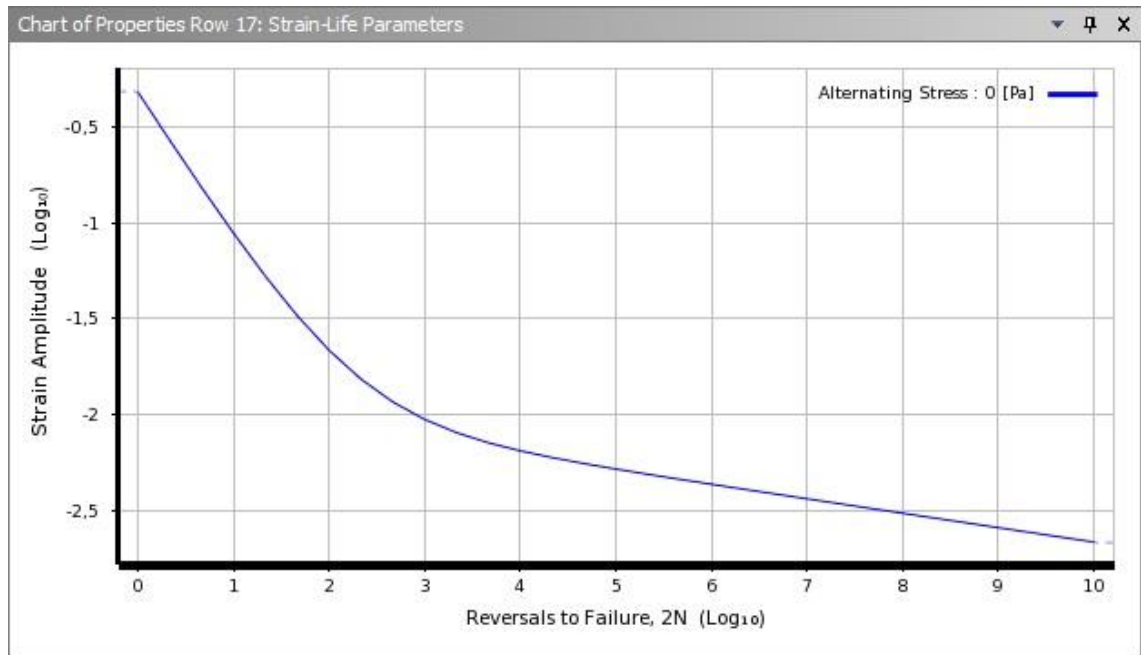


FIGURE 6. Strain-Life Parameters. ANSYS Workbench 14.5.

3.3 Introduction to Failure Analysis

Failure Analysis is an investigation carried out to determine the cause of failure of a certain product or equivalently the mistake in the continuous process of engineering design-manufacturing-performance in order to prevent its recurrence in the future.

With known loads and material; through a failure analysis, we can come to predict the future behavior of pieces.

3.3.1 Failure Analysis (Miner's Rule)

In 1945, M. A. Miner popularized a rule that had first been proposed by A. Palmgren in 1924.

The rule, variously called Miner's rule or the Palmgren-Miner (**EQ 7**) linear damage hypothesis, states that where there are k different stress magnitudes in a spectrum, S_i ($1 \leq i \leq k$), each contributing $n_i(S_i)$ cycles, then if $N_i(S_i)$ is the number of cycles to failure of a constant stress reversal S_i , failure occurs when:

$$\sum_{i=1}^k \frac{n_i}{N_i} = C \quad (\text{EQ 7})$$

C is experimentally found to be between 0.7 and 2.2. Usually for design purposes, C is assumed to be 1. This can be thought of as assessing what proportion of life is consumed by stress reversal at each magnitude then forming a linear combination of their aggregate.

Though Miner's rule is a useful approximation in many circumstances, it has several major limitations:

- 1- It fails to recognize the probabilistic nature of fatigue and there is no simple way to relate life predicted by the rule with the characteristics of a probability distribution. Industry analysts often use design curves, adjusted to account for scatter, to calculate N_i (S_i).
- 2- There is sometimes an effect in the order in which the reversals occur. In some circumstances, cycles of low stress followed by high stress cause more damage than would be predicted by the rule. It does not consider the effect of an overload or high stress which may result in a compressive residual stress that may retard crack growth. High stress followed by low stress may have less damage due to the presence of compressive residual stress.

4 SOFTWARES FOR DESIGN AND ANALYSIS 3D

There are two softwares used in this thesis. The first one for to do a design of the pieces and the other one for to do the analysis:

4.1 CATIA V5

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systèmes (PICTURE 6).



PICTURE 6. CATIA V5.

In our case, CATIA was used for a design a virtual "front hubs" and "rear hubs". The pieces were design with the most similar real dimensions.

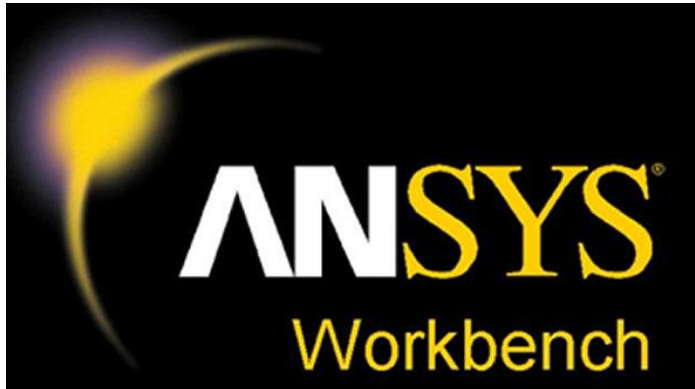
When CATIA design was finished, the new files were moved files to ANSYS.

4.2 ANSYS Workbench 14.5

ANSYS is an engineering simulation software (computeraided engineering, or CAE) developer that is headquartered in United States (PICTURE 7).

ANSYS offers engineering simulation solution sets in engineering simulation that a design process requires.

The tools put a virtual product through a rigorous testing procedure (such as crashing a car into a brick wall, or running for several years on a tarmac road) before it becomes a physical object.



PICTURE 7. ANSYS Workbench.

The new CAD files were used in ANSYS for to do different simulation tests.

In the first was necessary to apply some constants forces to obtain some results: equivalent stress, security factor, total deformation...

That information was used to compare with the numerical results obtained by mathematic calculus.

The last steps were to do with ANSYS a parametric analysis of pieces because not all loads play at the same time. Also is important to say who those forces really are variables.

With the final results (equivalent stress, security factor, total deformation...) is possible to see how works the hubs and what changes are necessary to do in CATIA design for to have better hubs.

5 HUBS OF THE WHEEL

In this chapter, the first point is to describe the initial conditions of the pieces. It's also included the basic calculation and ANSYS calculation of front and rear hubs.

5.1 Front Wheel Hub

The front wheel hub is the piece with most stress.

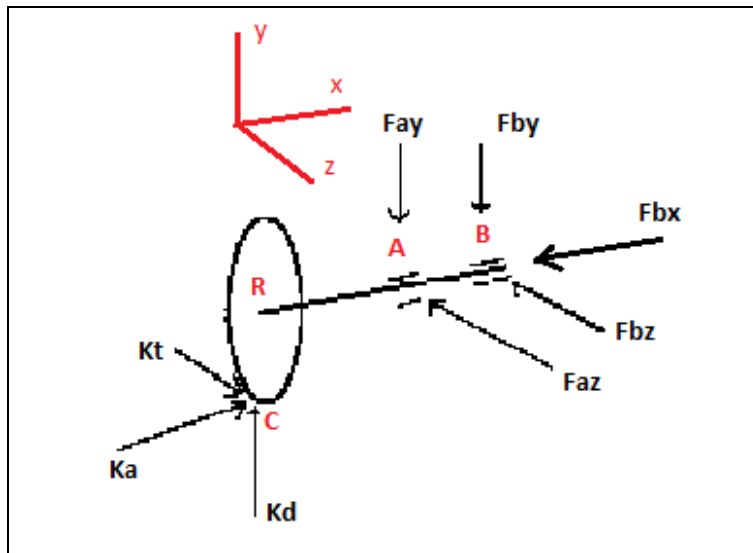
The basic design of this is lightest compared with the rear wheel hub and when the car is in the middle of the curve the front hub has a big forces applied, this kind of forces are more biggest when the car take the curve in a high speed.

Also, the front part of the car need endure the forces generates in the braking. These kinds of forces are biggest when the car arrives to the entrance of the curve in a high speed and the car used the brakes.

With this short introduction we arrive to one conclusion. The front piece needs to endure three variable forces.

Normal force generate in every time by the weight of the car (K_d), force generate by the friction of the wheels in the curves (K_a), and finally a force generate by the friction of the wheels when the car braking (K_t). (PICTURE 8).

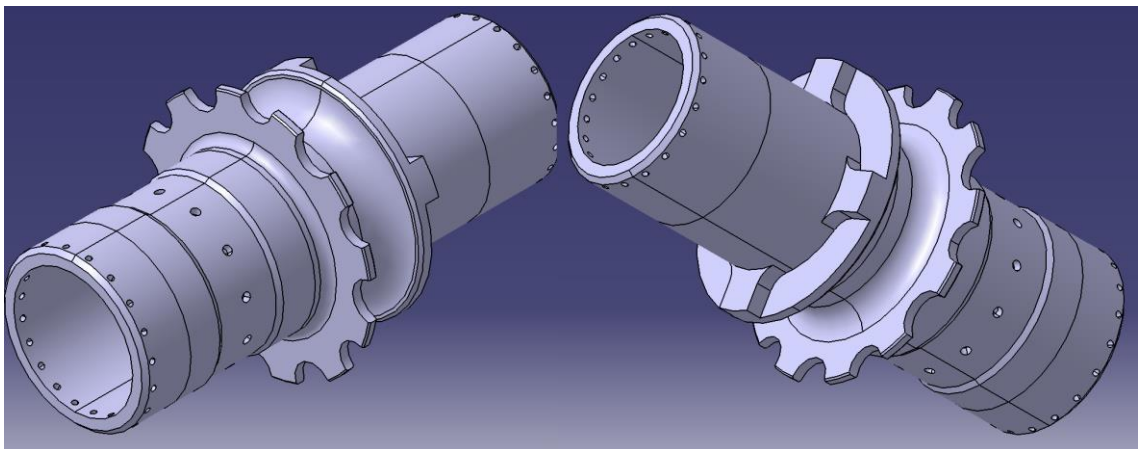
It's very important know which K_t and K_a don't work at the same time.



PICTURE 8. Forces distribution.

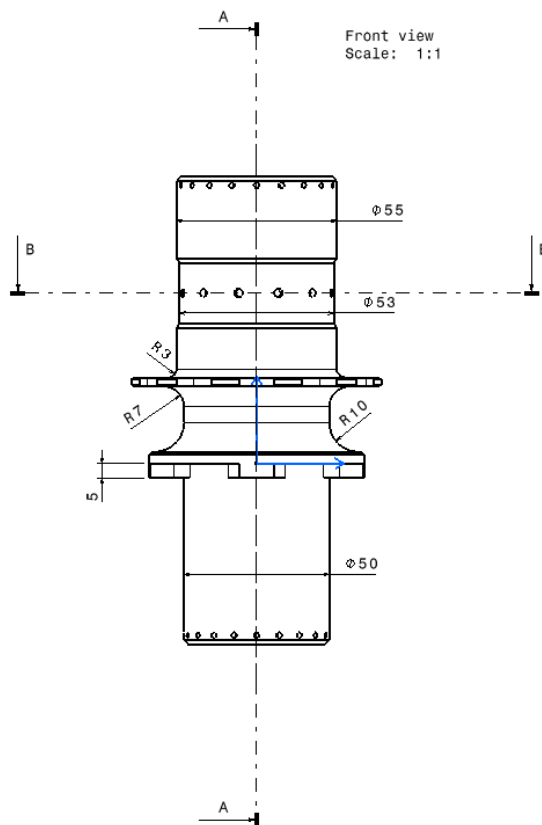
5.1.1 Initial Design (CATIA)

The initial design model of front hubs in CATIA is the next one: (PICTURE 9)

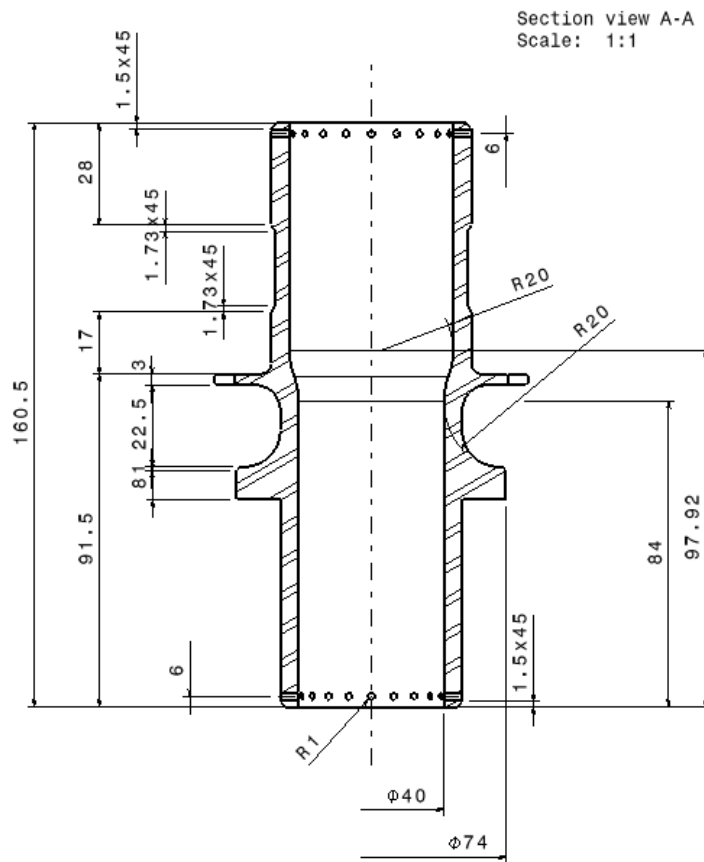


PICTURE 9. Front hub A. (Formula Team 2014).

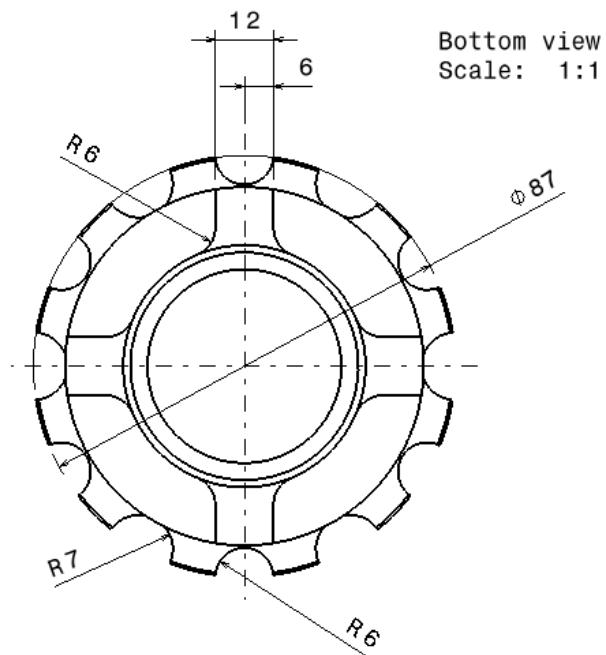
The most important dimensions are in the next pictures. (PICTURE 10, 11, 12, 13)



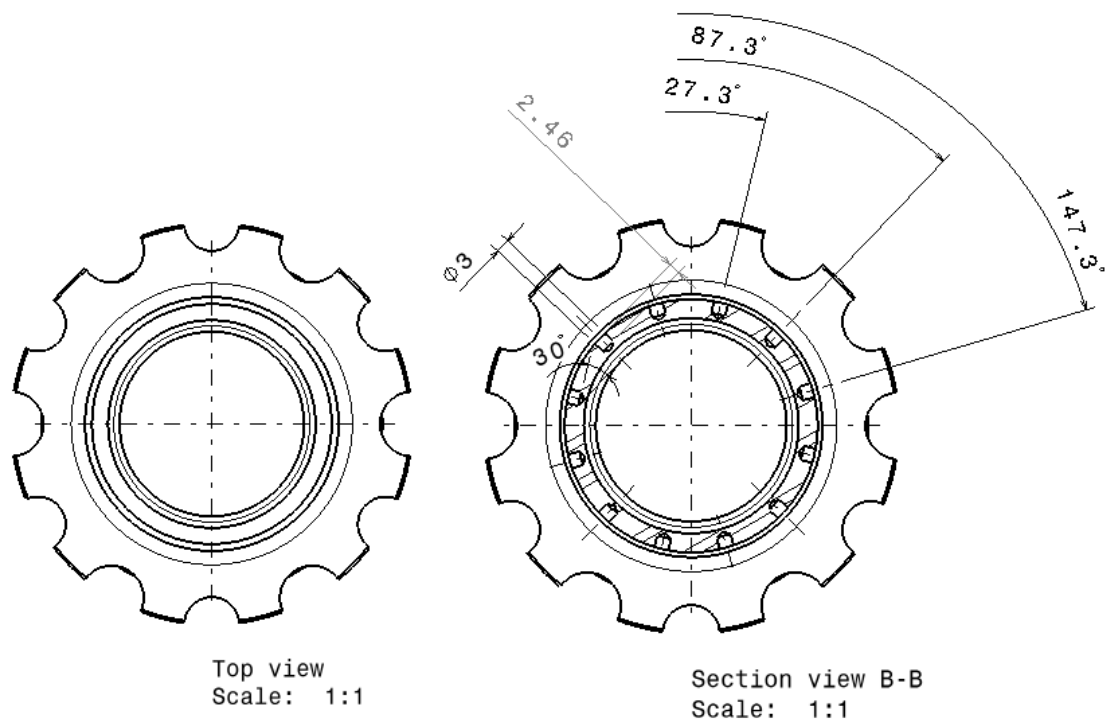
PICTURE 10. Front hub (Front view).



PICTURE 11. Front hub (Section view A-A).



PICTURE 12. Front hub (Bottom view).



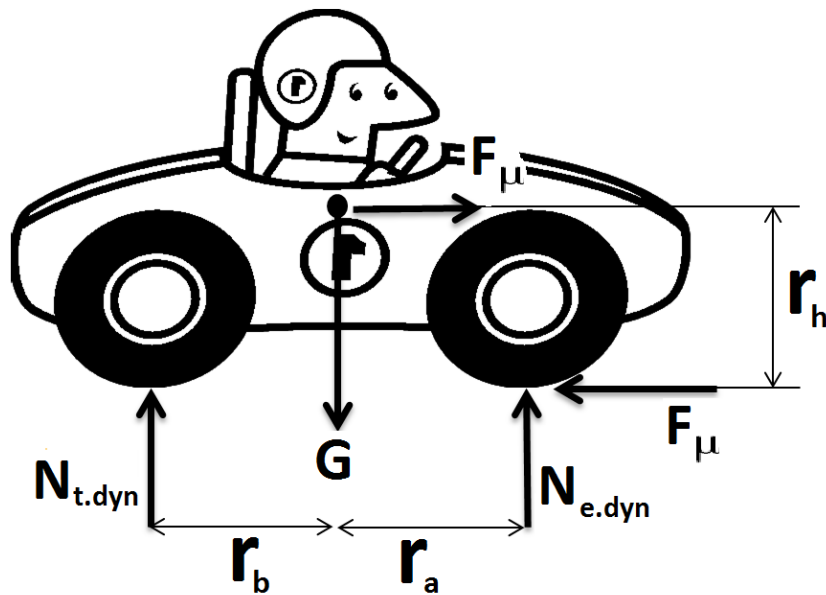
PICTURE 13. Front hub (Top view and section view B-B).

5.1.2 Mathematical Calculations

During this thesis work, the calculus of the first step was to do a study about the static weight distribution and dynamic weight distribution when the car is braking with the information initially given.

The most important part is the dynamic study braking (PICTURE 14).

With the dynamic study, is possible to get for different speeds what are the forces from braking (K_t), the front wheel vertical forces in corner (K_d), and the horizontal side force in corner (K_a) every moment.



PICTURE 14. Dynamic study braking.

There are the steps for to get the K_t , K_d and K_a :

$$G := m_I \cdot g$$

$$F_{\mu 1} := G \mu$$

$$F_{\mu 2} := F_{\text{d\'ec}} \mu$$

Balance equation:

$$\Sigma M_{.zb} = 0$$

$$\left[-(F_{\mu 1} + F_{\mu 2}) \cdot r_h - G r_b + (N_{e.dyn} - F_{dec}) \cdot (r_a + r_b) \right] = 0$$

$$\Sigma F_y := 0$$

$$G = N_{e.dyn} + N_{t.dyn} - F_{dec}$$

For one wheel:

$$N_e := \frac{N_{e.dyn}}{2}$$

$$N_t := \frac{N_{t.dyn}}{2}$$

The calculation of the first force K_t :

Force from braking (front):

$$K_{t1} := N_e \cdot \mu \quad \text{(EQ 8)}$$

Force from braking (rear):

$$K_{t2} := N_t \cdot \mu \quad \text{(EQ 9)}$$

The next step is calculating the side forces in corners with same principle:

Balance equation:

$$\Sigma M_{za1} := 0$$

$$\left[(F_{\mu 1} + F_{\mu 2}) \cdot r_h - N_{s1.dyn} \cdot (r_{as} + r_{as}) + (G + F_{dec}) \cdot r_{as} \right] = 0$$

$$\Sigma F_y := 0$$

$$G = N_{s1.dyn} + N_{s2.dyn} - F_{dec}$$

For one wheel:

$$N_{s1} := \frac{N_{s1.dyn}}{2}$$

$$N_{s2} := \frac{N_{s2.dyn}}{2}$$

Now is possible to get the rest of forces (Kd and Ka):

Vertical force in corner (front):

$$\overline{K_{d1}} := N_{s1} \quad (\text{EQ 10})$$

Vertical force in corner (rear):

$$\overline{K_{d2}} := N_{s2} \quad (\text{EQ 11})$$

Horizontal side force in corner (front):

$$\overline{K_{a1}} := N_{s1} \cdot \mu \quad (\text{EQ 12})$$

Horizontal side force in corner (rear):

$$\overline{K_{a2}} := N_{s2} \cdot \mu \quad (\text{EQ 13})$$

Then:

When the car is accelerating, in the front wheel there are the next forces:

Kd3 and Kt3

(Kd3 and Kt3 calculation in paragraph 5.2.2; **EQ 16** and **EQ 14**)

When the car is in the middle of the curve, in the front wheel there are the next forces:

Kd1+Kd3 and Ka1+Ka3

(Kd3 and Ka3 calculation in paragraph 5.2.2; **EQ 10 + EQ 16** and **EQ 12 + EQ 18**)

When the car is decelerating, in the front wheel there are the next forces:

Kd1 and Kt1

(**EQ 10** and **EQ 8**)

5.2 Rear Wheel Hub

The rear wheel hub is not the piece with most stress but it need endure different forces.

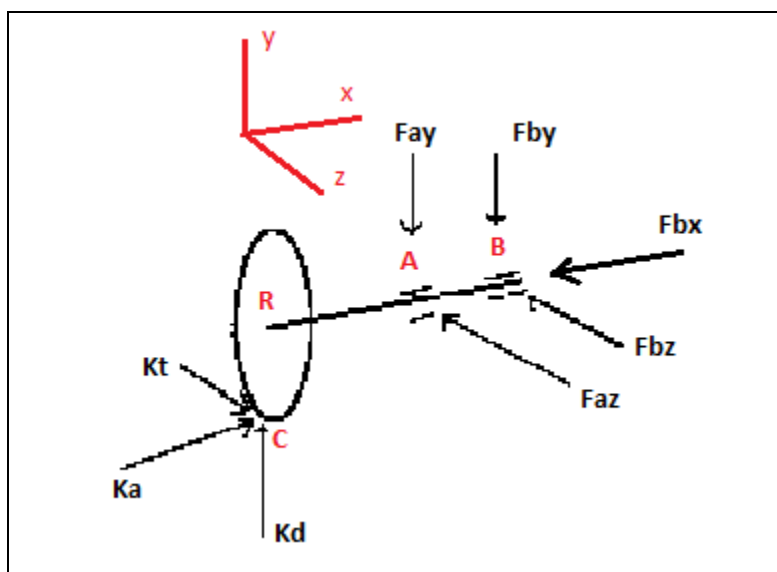
The design of this is biggest compared with the front wheel hub and when the car is in the middle of the curve the rear hub has a big forces applied, this kind of forces are more biggest when the car take the curve in a high speed.

Also, the rear part of the car need endure the forces generates in the acceleration. These kinds of forces are biggest when the car starts from the end of the curve to the next curve in a slow speed.

With this short introduction in this thesis likely arrive to one conclusion. The front piece need endure three variable forces.

Normal force generate in every time by the weight of the car (K_d), force generate by the friction of the wheels in the curves (K_a), and finally a force generate by the friction of the wheels when the car is accelerating (K_t). (PICTURE 15).

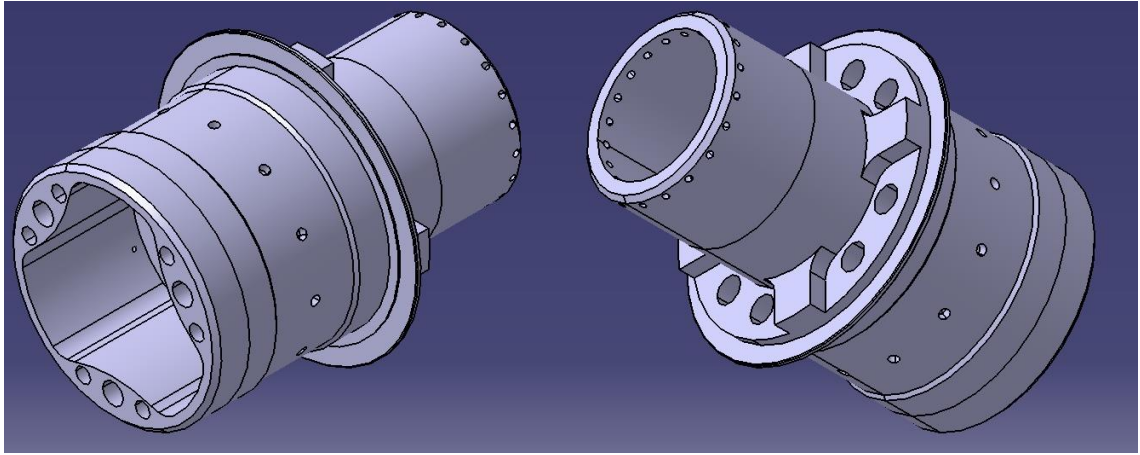
Is very important know which K_t and K_a don't work at the same time.



PICTURE 15. Forces distribution II.

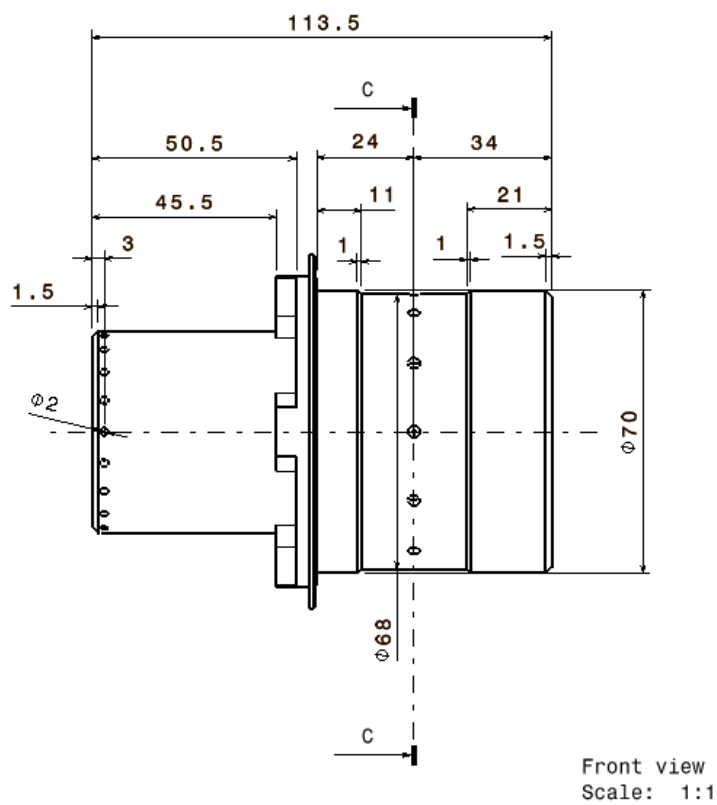
5.2.1 Initial Design (CATIA)

The initial design model of rear hubs in CATIA is the next one: (PICTURE 16).

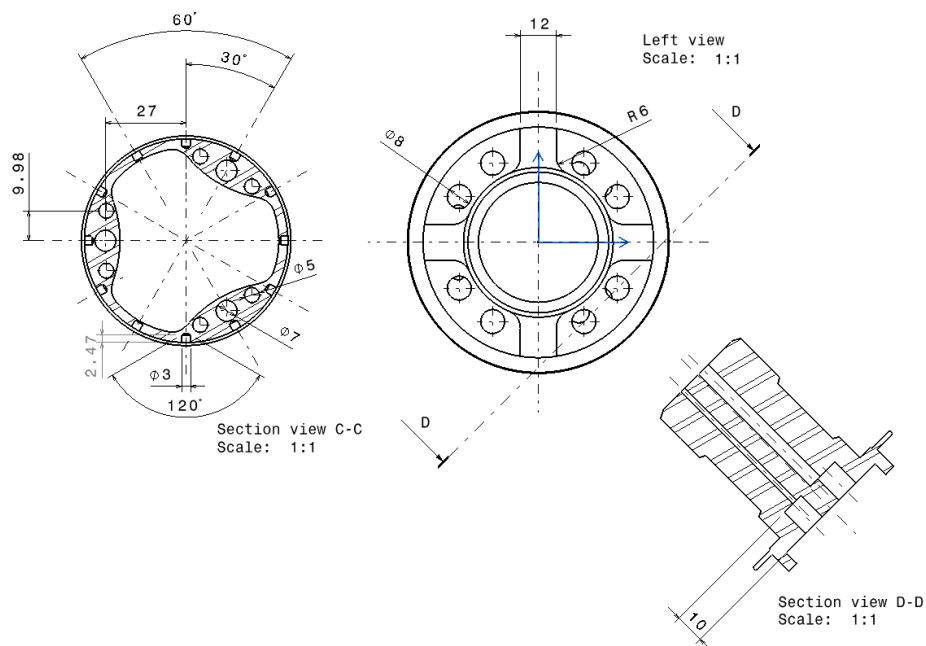


PICTURE 16. Rear hub A. (Formula Team 2014).

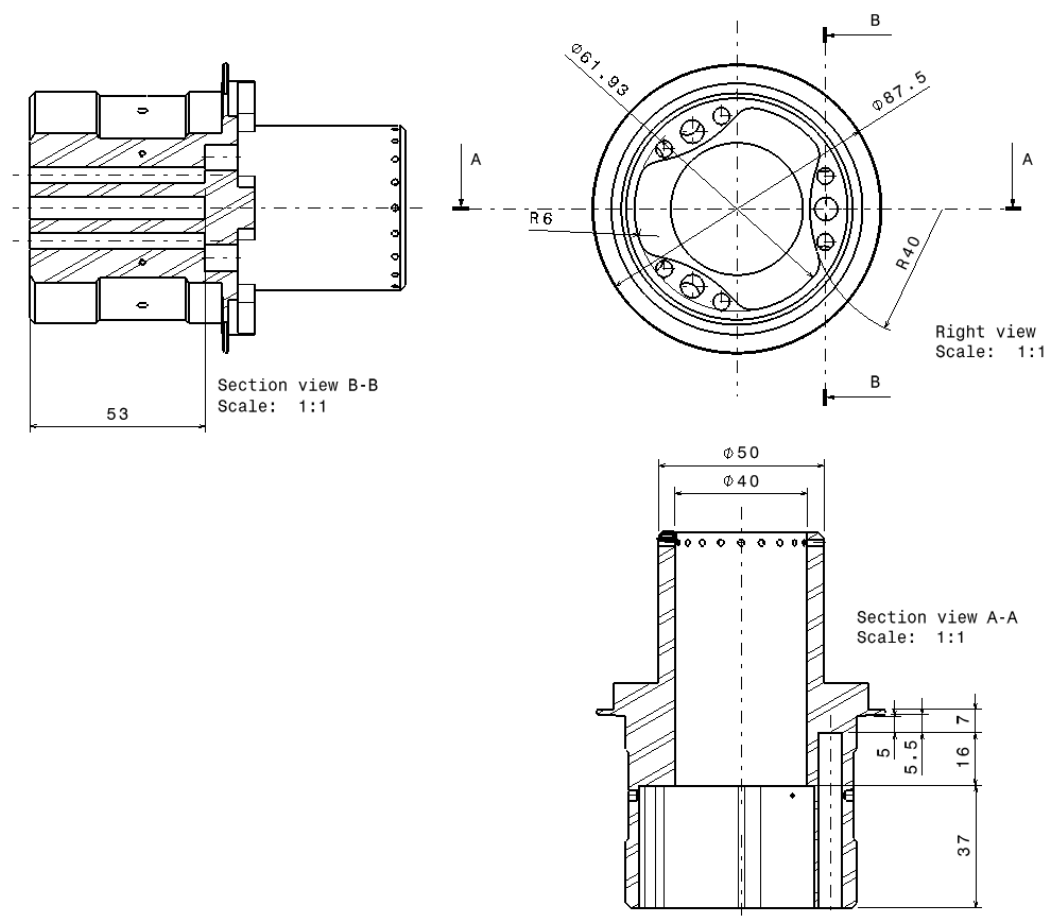
The most important dimensions are in the next pictures. (PICTURE 17, 18, 19)



PICTURE 17. Rear hub (Front view).



PICTURE 18. Rear hub (Section view C-C, Left view and Section view D-D).



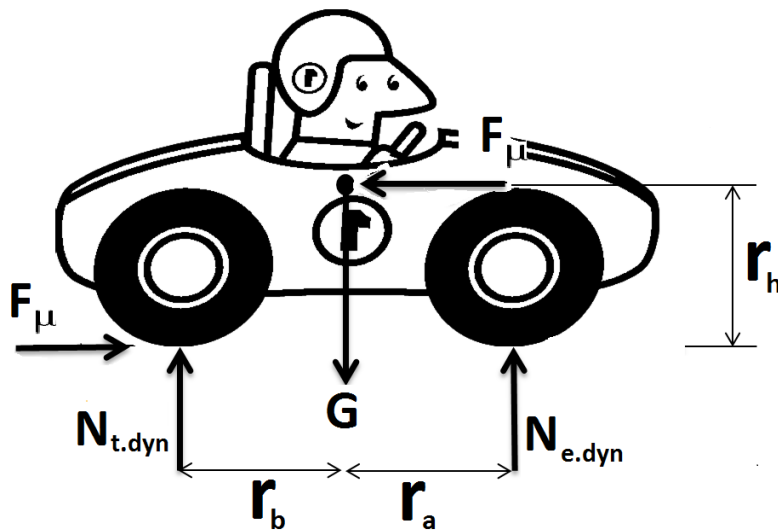
PICTURE 19. Rear hub (Section view B-B, Right view and Section view A-A).

5.2.2 Mathematical Calculations

Too during this thesis work, the calculus of the first step was to do a study about the static weight distribution and dynamic weight distribution when the car is accelerating with the information initially given.

The most important part is the dynamic study accelerating (PICTURE 20).

With the dynamic study, is possible to obtain in different speeds what are the forces from braking (K_t), the front wheel vertical forces in corner (K_d), and the horizontal side force in corner (K_a) every moment.



PICTURE 20. Dynamic study accelerating.

There are the steps for to get the K_t , K_d and K_a :

$$\underline{\underline{G := m_I \cdot g}}$$

$$\underline{\underline{F_{\mu 1} := G \cdot \mu}}$$

$$\underline{\underline{F_{\mu 2} := F_{ac} \cdot \mu}}$$

Balance equation

$$\Sigma M_{za} := 0$$

$$\underline{\underline{F_{\mu 1} \cdot r_h + F_{\mu 2} \cdot r_h + G \cdot r_a + F_{ac} \cdot (r_a + r_b) - N_{t.dyn} \cdot (r_a + r_b) = 0}}$$

$$\Sigma F_y := 0$$

$$G = N_{e,dyn} + N_{t,dyn} - F_{ac}$$

For one wheel:

$$N_{e2} := \frac{N_{e,dyn}}{2}$$

$$N_{t2} := \frac{N_{t,dyn}}{2}$$

The calculation of the first force K_t :

Force from acceleration (front):

$$K_{t3} := N_{e2} \cdot \mu \quad (\text{EQ 14})$$

Force from acceleration (rear):

$$K_{t4} := N_{t2} \cdot \mu \quad (\text{EQ 15})$$

The next step is calculating the side forces in corners with same principle:

Balance equation:

$$\Sigma M_{az2} := 0$$

$$\left((F_{\mu1} + F_{\mu2}) \cdot r_h - N_{s1,dyn} \cdot (r_{as} + r_{as}) + G r_{as} + F_{ac} \cdot r_{as} \right) = 0$$

$$\Sigma F_y := 0$$

$$G = N_{s1,dyn} + N_{s2,dyn} - F_{ac}$$

For one wheel:

$$N_{s1} := \frac{N_{s1,dyn}}{2}$$

$$N_{s2} := \frac{N_{s2,dyn}}{2}$$

Now is possible to get the rest of forces (K_d and K_a):

Vertical force in corner (front):

$$K_{d3} := N_{s2} \quad (\text{EQ 16})$$

Vertical force in corner (rear):

$$K_{d4} := N_{s1} \quad (\text{EQ 17})$$

Horizontal side force in corner (front):

$$K_{a3} := N_{s2} \cdot \mu \quad (\text{EQ 18})$$

Horizontal side force in corner (rear):

$$K_{a4} := N_{s1} \cdot \mu \quad (\text{EQ 19})$$

Then:

When the car is accelerating, in the rear wheel there are the next forces:

K_{d4} and K_{t4}

(EQ 17 and EQ 15)

When the car is in the middle of the curve, in the rear wheel there are the next forces:

K_{d2}+K_{d4} and K_{a2}+K_{a4}

(K_{d2} and K_{a2} calculation in paragraph 5.1.2; EQ 11 + EQ 17 and EQ 13 + EQ 19)

When the car is decelerating, in the rear wheel there are the next forces:

K_{d2} and K_{t2}

(K_{d2} and K_{t2} calculation in paragraph 5.1.2; EQ 11 and EQ 9)

5.3 FATIGUE ANALYSIS

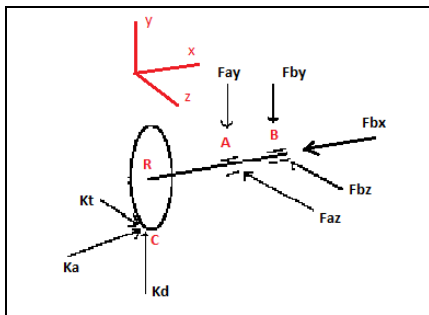
With real forces the next step is to do a basic analysis of pieces.

5.3.1 Basic Calculation

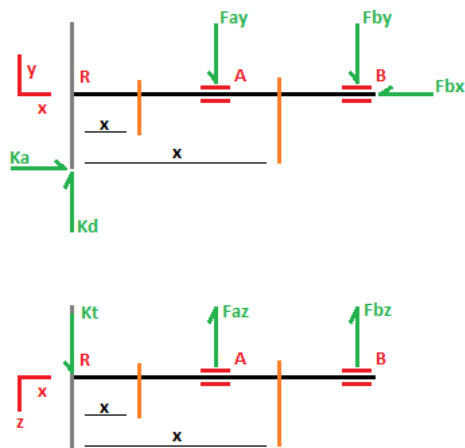
In this point is the explanation about how to do the basic calculation necessary for design hubs without computer.

But this calculation is not accurate because this design process of the piece for a fatigue is with the maximum stress. It is not a design for a fatigue with cumulative damage.

There is the calculation process (Is necessary to do it in every hub):



PICTURE 21. Forces distribution II.



PICTURE 22. Forces distribution II.

BASIC SUMMATIONS:

Is necessary to do these equations to obtain the reactions:

$$\Sigma F_x := 0$$

$$K_a - F_{bx} = 0$$

$$\Sigma F_y := 0$$

$$K_d - F_{ay} - F_{by} = 0$$

$$\Sigma F_z := 0$$

$$K_t - F_{az} - F_{bz} = 0$$

$$\Sigma M_{z_a} := 0$$

$$-K_d \cdot (RA) + K_a \cdot (RC) - F_{by} \cdot (AB) = 0$$

$$\Sigma M_{y_a} := 0$$

$$K_t \cdot (RA) + F_{bz} \cdot (AB) = 0$$

View details of forces distribution in PICTURE 21 and PICTURE 22.

It's important remember who the maximum stress is when $K_t=0$.

With the reactions, is possible do the diagrams of forces (N, T_y , T_z), bending (M_y , M_z) and torsion (M_x).

With the diagrams and with the next formulas is possible to find the most stressed section:

$$A = \pi \cdot (R^2 - r^2)$$

$$I_{zz} = I_{yy} = \frac{\pi \cdot (R^4 - r^4)}{4}$$

$$\sigma = \frac{N}{A} - \frac{M_z}{I_{zz}} \cdot y + \frac{M_y}{I_{yy}} \cdot z$$

$$\tau = \tau_{max} = 2 \cdot \left(\frac{T_y}{A} \right)$$

$$\sigma_{eq} = \sqrt{\sigma^2 + 3 \cdot \tau^2}$$

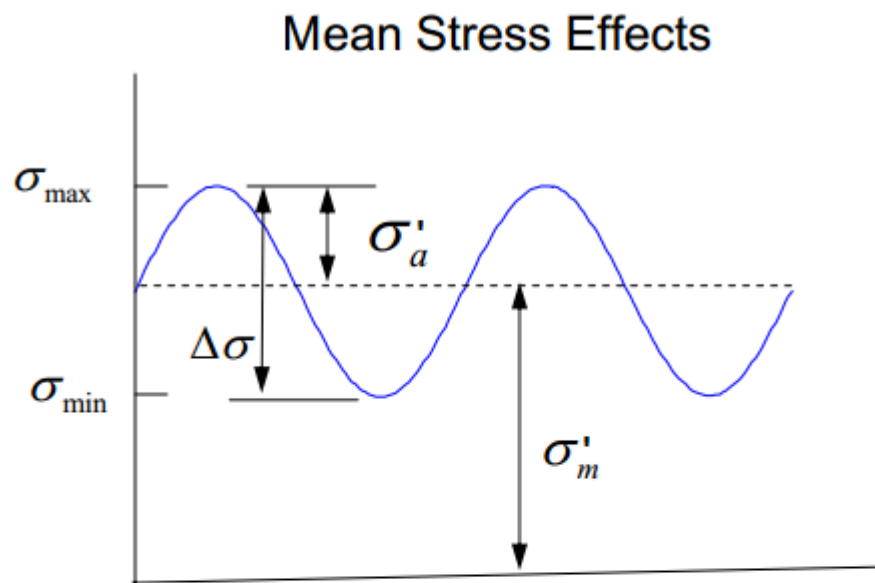
Now and after this point, is necessary to do the fatigue analysis.

FATIGUE ANALYSIS:

In fatigue analysis the first step is to take σ_{eq} (σ_{max}) with the biggest force (it depends of the speed) in the most stressed section.

Also is necessary to take σ_{eq} (σ_{min}) with the smaller force (it depends of the speed) in the same section.

Now the next step is to add these valors in the next equations and calculate the “Mean Stress Effects” (FIGURE 7):



$\Delta\sigma = \sigma_{\max} - \sigma_{\min}$	stress range
$\sigma'_a = \frac{\Delta\sigma}{2} = \frac{\sigma_{\max} - \sigma_{\min}}{2}$	alternating stress
$\sigma'_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}$	mean stress

FIGURE 7. Mean Stress Effects. Fundamentals of Metal Fatigue Analysis.

After this calculation is time to attack the material calculations for an Aluminum alloy 7075-T6.

The information of the material is $\sigma_u=572\text{MPa}$; $\sigma_{lim}=\sigma_y=503\text{MPa}$.

First is necessary to do an adjustment in EL (Endurance Limit, fatigue strength of test specimen) of the material.

This adjustment of the EL is the result of six fractional factors.

Each of these six factors is calculated from known data which describe the influence of a specific condition on fatigue life.

Those factors are:

(a) Surface Condition (K_a): such as: polished, ground, machined, as-forged, corroded, etc. Surface is perhaps the most important influence on fatigue life;

(b) Size (K_b): This factor accounts for changes which occur when the actual size of the part or the cross-section differs from that of the test specimens;

(c) Load (K_c): This factor accounts for differences in loading (bending, axial, torsional) between the actual part and the test specimens;

(d) Temperature (K_d): This factor accounts for reductions in fatigue life which occur when the operating temperature of the part differs from room temperature (the testing temperature);

(e) Reliability (K_e): This factor accounts for the scatter of test data. For example, an 8% standard deviation in the test data requires a k_e value of 0.868 for 95% reliability, and 0.753 for 99.9% reliability.

(f) Miscellaneous (K_f): This factor accounts for reductions from all other effects, including residual stresses, corrosion, plating, metal spraying, fretting, and others.

$$\text{Cyclic Stress} = K_a * K_b * K_c * K_d * K_e * K_f * E_L$$

$$\text{Cyclic Stress} = \sigma'_e = K_a * K_b * K_c * K_d * K_e * K_f * (0,5 * \sigma_u)$$

The next step is to choose what kind of Stress Methods we will to use (FIGURE 8):

- Goodman method: generally suitable for brittle materials
- Gerber method: generally suitable for ductile materials
- Soderberg method: generally the most conservative

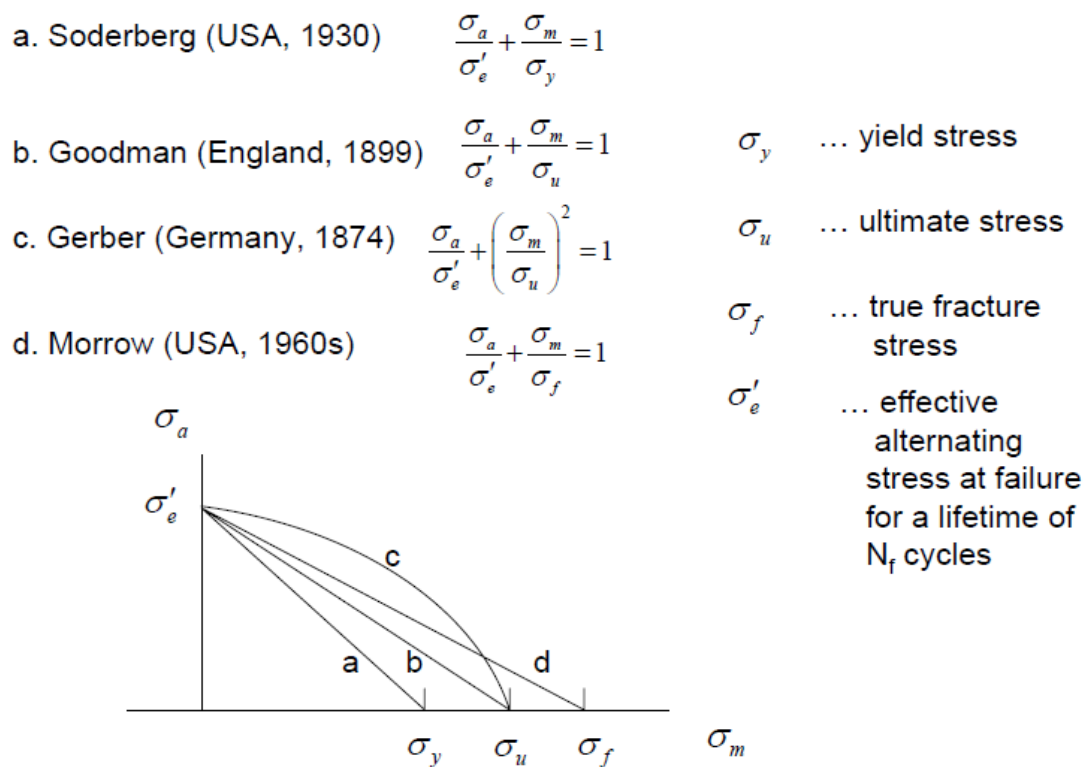


FIGURE 8. Empirical curves to estimate mean stress effects on fatigue life

For example in a Goodman design ($\sigma'_e = \sigma_e$), it's happen (FIGURE 9):

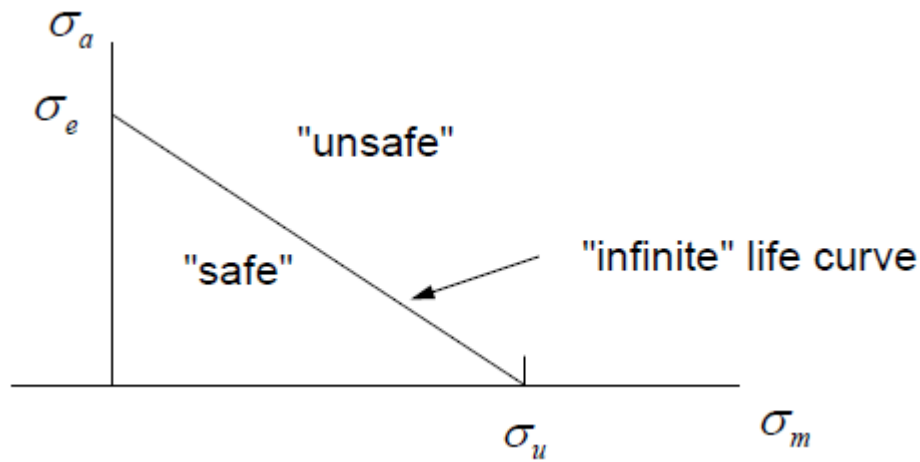


FIGURE 9. Safe area in Goodman design

It's necessary to check if the design are in safe zone or unsafe zone (with our variables σ'_a and σ'_m).

If we want to do a redesign is necessary to do a load line.

For an infinite life (FIGURE 10), it's solving a system of equations with the specific Stress Method equation and this one:

$$\frac{\sigma'_a}{\sigma'_m} \cdot \sigma_m = \sigma_a$$

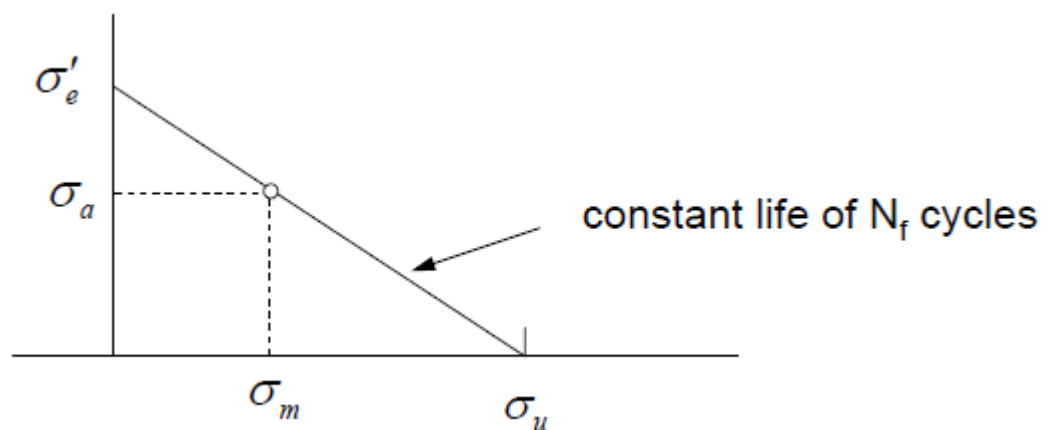


FIGURE 10. Line of Infinite life

Finally in the last step, using this effective alternating stress, determine the lifetime for this stress (and the corresponding original alternating and mean stresses) from the S-N diagram for the given material (FIGURE 11):

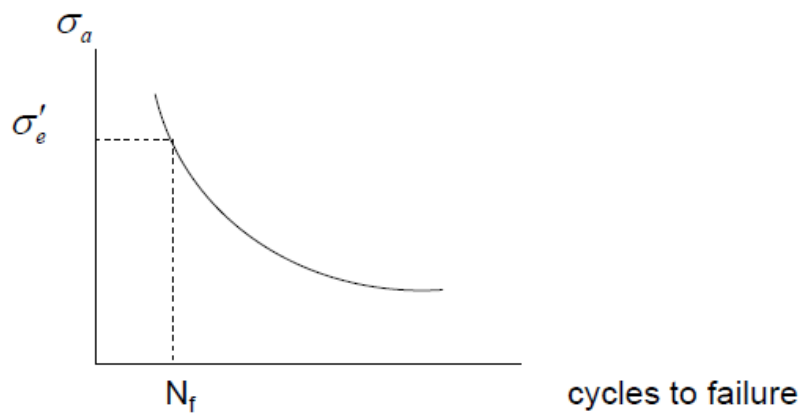


FIGURE 11. Cycles to failure.

5.3.2 Calculation with ANSYS Workbench

ANSYS does a parametric analysis to obtain results.

First, it's important to upload CATIA pieces in ANSYS software.

The next step is to add the information about material: Aluminum Alloy 7075-T6 (TABLE 2).

Also, it's important to add in ANSYS the forces in every part of the circuit. These forces are K_a , K_d and K_t for the front and the rear wheel hub.

We calculated these forces by method that is described in points 5.1 and 5.2.

In the next plot (FIGURE 12) we have the forces of the front and the rear hubs for one lap (73seconds):

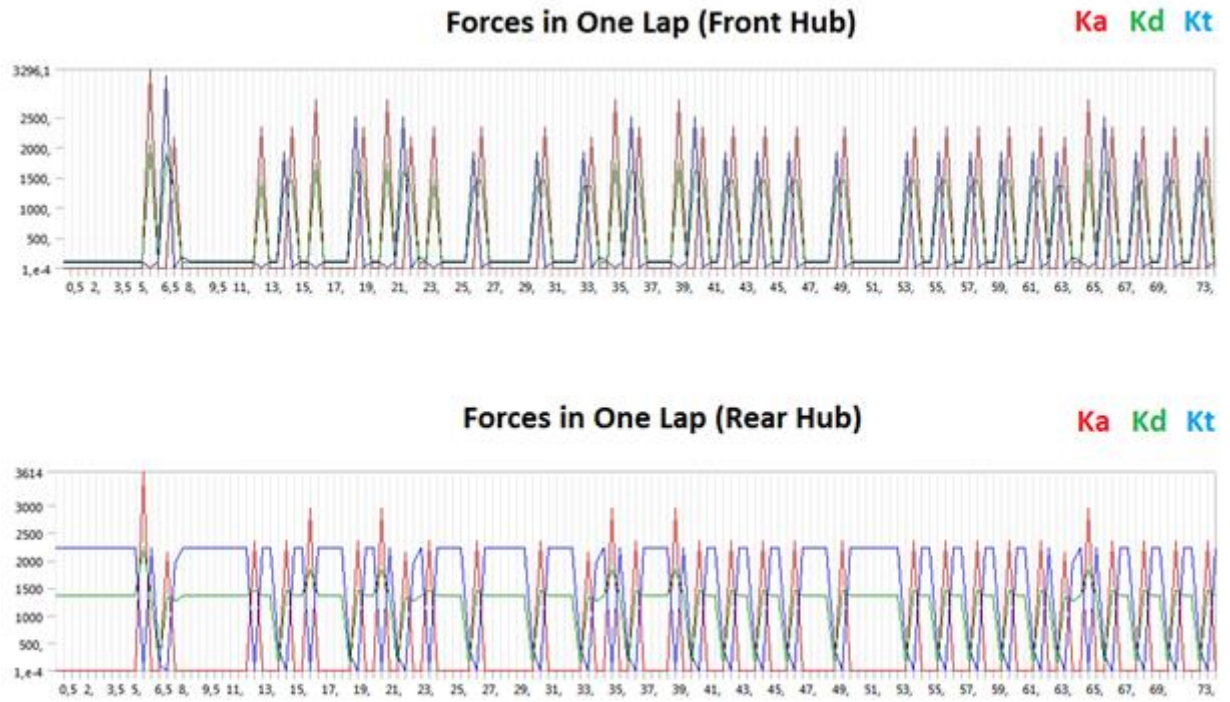
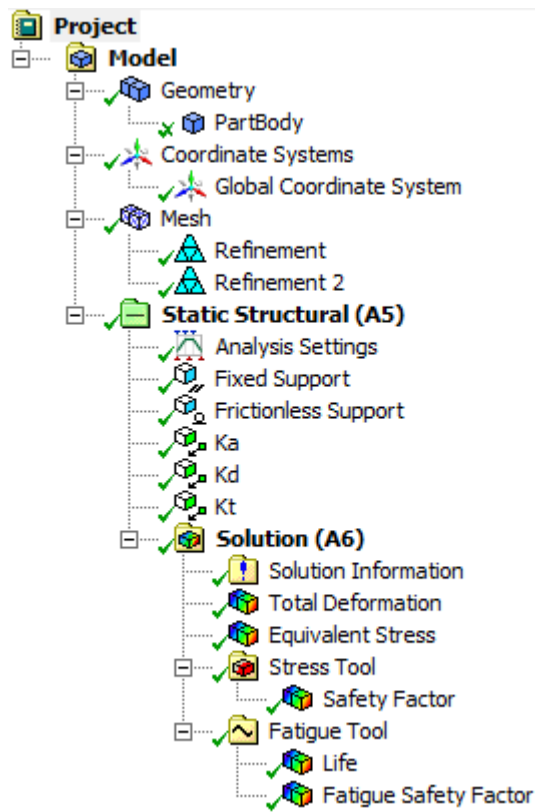


FIGURE 12. Hubs forces. ANSYS Workbench 14.5.

Also, these forces are described in Appendix 1.

The final step is to say to ANSYS which type of analysis we want.

In this case, we want to do a fatigue analysis, but is possible to get more information at the same time (solutions). One example about it is in the next picture (PICTURE 23):



PICTURE 23. Example of Solutions. ANSYS Workbench 14.5.

6 RESULTS

This section includes final results

6.1 Fatigue Analysis on Original Pieces (ANSYS)

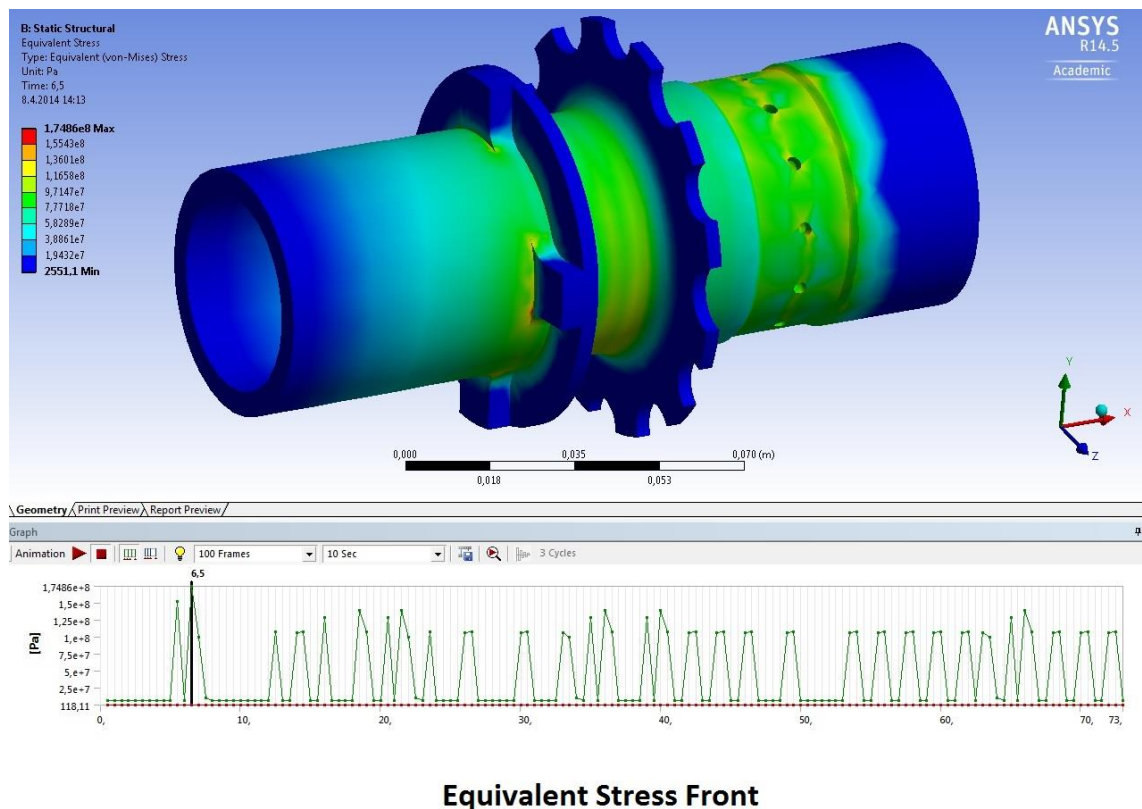
“Fatigue Analysis on Original Pieces” includes test results when they are applied in Miner’s Rule.

6.1.1 Front Hub

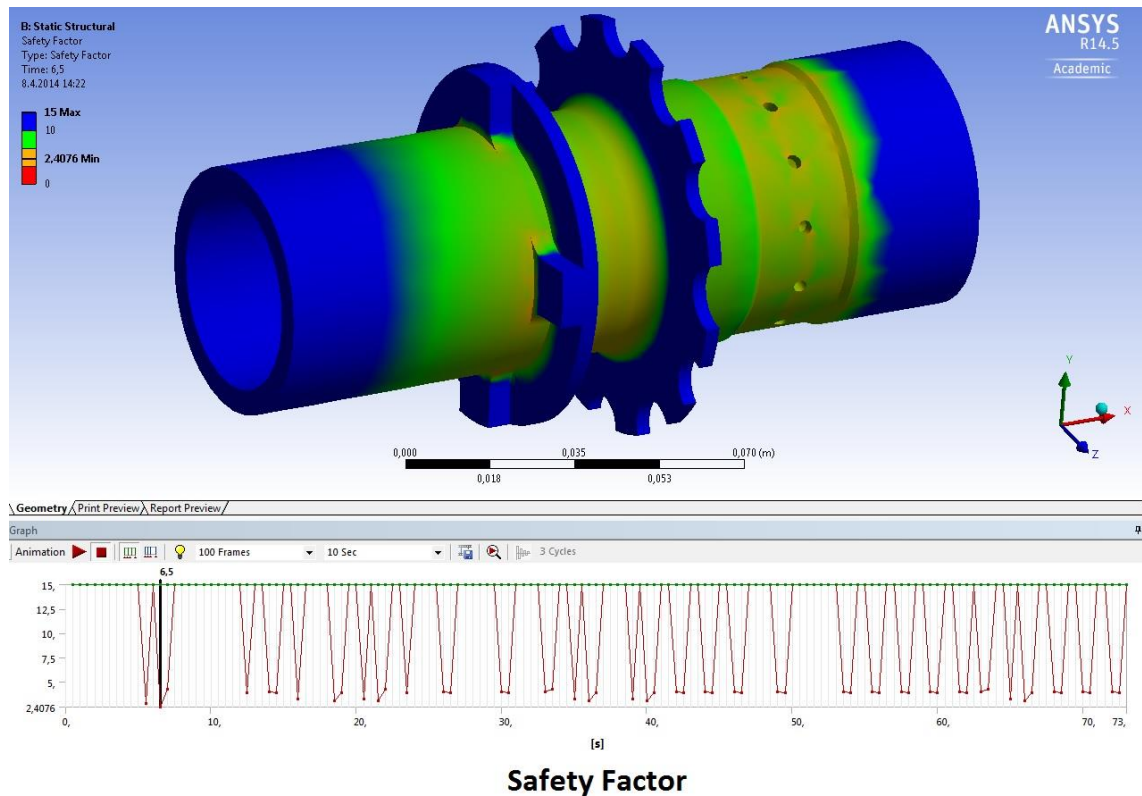
After the analysis, ANSYS can offer different results.

In the next pictures are shown the obtained results for an Equivalent Stress (PICTURE 24) and the Security Factor (PICTURE 25) of front piece with K_a , K_d and K_t forces.

It’s possible to look those parts with more stress are parts with big changes in the shape of the piece. Then, the piece can start to breaking in these parts.



PICTURE 24. Equivalent Stress in Front. ANSYS Workbench 14.5.



PICTURE 25. Safety factor in Front. ANSYS Workbench 14.5.

But the real important thing in this analysis is the results of the life in a fatigue test.

This is the calculation:

First step is to calculate the cycles of life for the piece, because we need apply this result in the next steps.

TABLE 3. Laps who we need endure

GERMANY			TOIJALAN		
Endurance	22 laps		Test season	700 laps	
Autocross	4 laps		DISTANCE OF CIRCUIT	0,8 km	
Skid pad	2 laps				
Test	3 laps				
TOTAL I	31 laps				
SIMILAR CIRCUITS	5 circuits				
TOTAL II	155 laps				
DISTANCE OF CIRCUIT	1 km/lap				
TOTAL III	155 km	155000 m	TOTAL I	560 km	560000 m
TOTAL					715000 m

The piece needs endure 715 laps. In number of cycles it is 497795 cycles (TABLE 3, 4).

TABLE 4. Cycles of life

WHEEL		
DIAMETER	457,2 mm	0,4572 m
R	228,6 mm	0,2286 m
PERIMETER	$P=2*PI*R$	1,436336 m
CYCLES	497794,33	497795

The next step is to know in one lap how many times we are in the different speeds (TABLE 5):

TABLE 5. Percentage of speed/steps.

SPEED	20	50	90	120	KM/H		
STEPS	8	127	10	2	STEPS	147	STEPS
PERCENTAGE	5,442177	86,39456	6,802721	1,360544	%	100	%
total B	0	17	5	1		B=Braking	
total C	4	21	5	1		C=Curve	
total A	4	89	0	0		A=Accelerating	

With this information, the exact number of cycles in every speed can be obtained (TABLE 6):

TABLE 6. Cycles in every speed

N=	497795	cycles
n1 (20km/h)	27090,88	cycles
n2 (50km/h)	430067,8	cycles
n3 (90Km/h)	33863,61	cycles
n4 (120km/h)	6772,721	cycles

Finally with this information, with the information obtained from ANSYS about the fatigue life and with Miner's rule, it is apt to obtain if the front hub endure or if is necessary modify it (Appendix 2):

D_lab	0,947324246	
D_lab < 1	OKAY! It endures	
It needs endure	715	Laps
It endures	105,5604777	% Laps
Endure Laps	754,7574159	Laps

Is possible improve the calculation applying the next condition:

If the step has infinite life, it is equal to 0 ($\infty_{\text{life}}=0$) in the summation.

This condition is in Appendix 3.

D_lab	0,563480278	
D_lab < 1	OKAY! It endures	
It needs endure	715	Laps
It endures	177,4685004	%
Endure Laps	1268,899778	Laps

We can check who the design of the front hub is correct.

It isn't necessary modify.

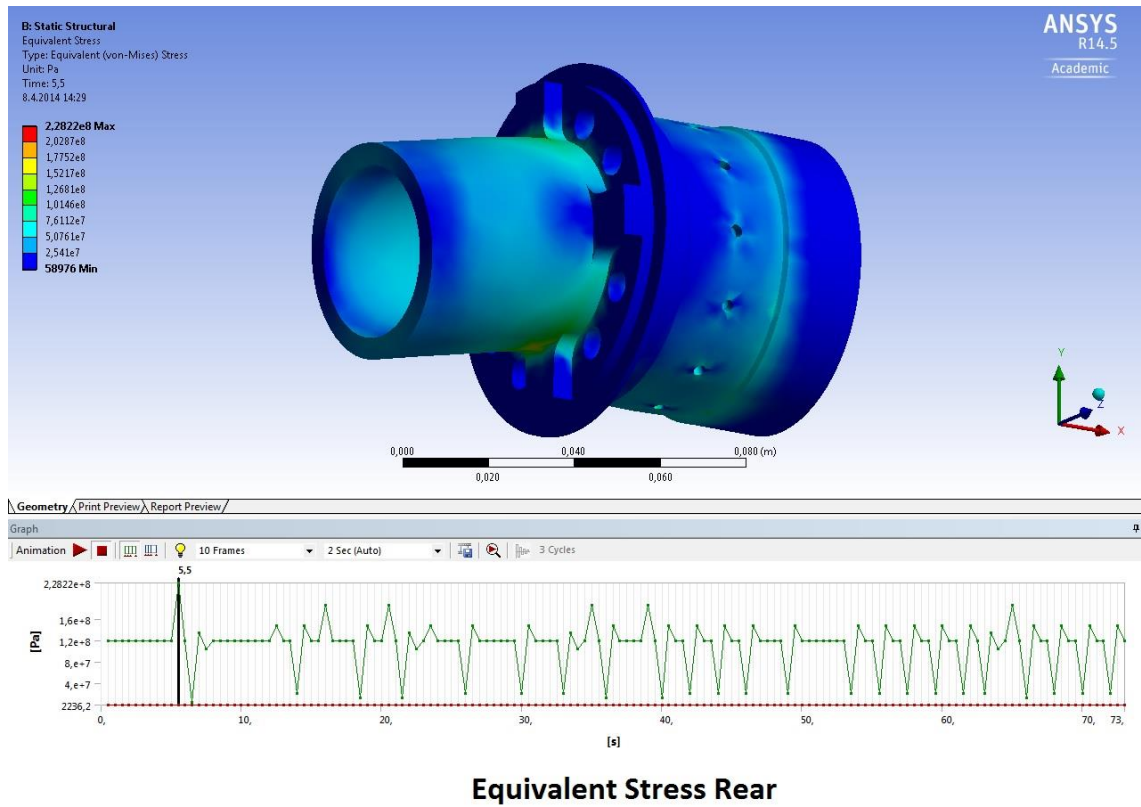
6.1.2 Rear Hub

The same who the front hub, with this analysis we can check different results.

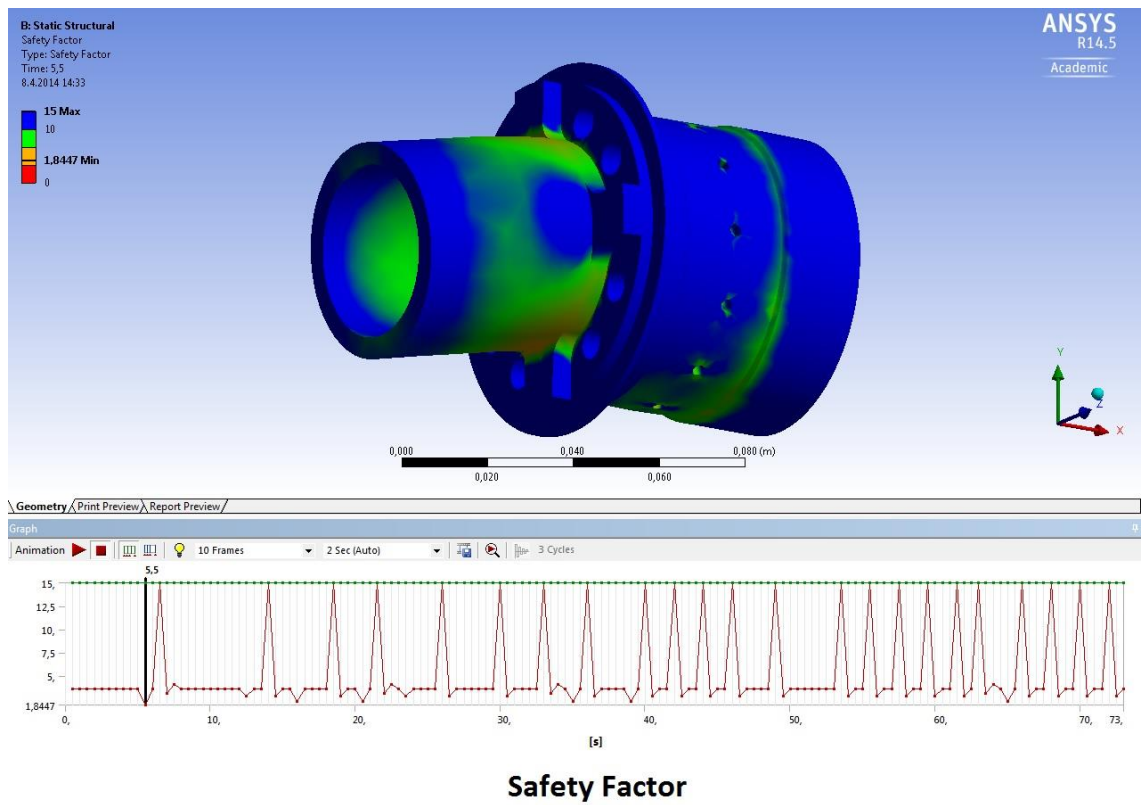
In the next pictures will be shown too an obtained results for an Equivalent Stress (PICTURE 26) and the Security Factor (PICTURE 27) of rear piece with K_a , K_d and K_t forces.

Parts with more stress are too parts with big changes in the shape of the piece too.

Then, the piece can start to breaking in these points.



PICTURE 26. Equivalent Stress in Rear. ANSYS Workbench 14.5.



PICTURE 27. Safety factor in Rear. ANSYS Workbench 14.5.

But the real important thing in this analysis is too the results of the life in a fatigue test. The calculation is the same who in the front hub.

With the information about cycles in every step, with the information obtained from ANSYS about the fatigue life and with Miner's rule, is possible to obtain if the rear hub endure or if is necessary modify it (Appendix 4):

D_lab	30,81066376	
D_lab > 1	BAD It will breaks	
It needs endure	715	Laps
It endures	3,245629526	% Laps
Endure Laps	23,20625111	Laps

Is possible improve the calculation applying the next condition:

If the step has infinite life, it is equal to 0 ($\infty_life=0$) in the summation.

This condition is in Appendix 5.

D_lab	30,73579132	
D_lab > 1	BAD It will breaks	
It needs endure	715	Laps
It endures	3,253535884	% Laps
Endure Laps	23,26278157	Laps

We can check who the design of the rear hub isn't good.

The calculation says that is necessary to modify it.

6.2 Analysis of Fatigue Results (ANSYS)

This section includes a short review about ANSYS results.

6.2.1 Front Hub

With this results, in the front hub is not necessary to do any modifications, also is important to say that maybe the study of the front hub can be good or similar to the real

behavior, because the high forces happen only in short times when the car is braking, although in this thesis is supposed the speeds in every part of the track because the team doesn't have more information about it, we really know a speeds of the car when it's braking.

Also we know that the team used these hubs the last year in the same competition and hubs endured all season.

6.2.2 Rear Hub

With the results that we obtained we will need to do some modifications in the piece because the calculus says that the piece will breaks.

But really, the fatigue calculus part of this study of the rear wheel hub can be wrong because the team used these hubs the last year in the same competition and hubs endured all season.

The problem of this results will be in the study of the forces who are apply in the rear hub because in this thesis it's supposed some ideal speeds because we don't have a real behavior for every time.

Maybe the mistake can be when we supposed the same speed (50km/h) during the right ways but in real life these don't happen and these affect to our percent of the cycle in every speed (TABLE 6) if this percent is low the summation results are low.

Also to the forces when we are in straightway can change.

Is possible to check in the appendix 4 or appendix 5(forces in rear wheel). In the last column of the appendix, the percent of the forces when the car is in 50km/h is high.

Then if we modify it may be the solution can be change.

This mistake doesn't happen in the front wheel because only affect when the car is accelerating, then it's happening only in the rear hubs.

In the front hub during the accelerating forces are smaller than in the rear hub.

7 PROPOSED CHANGES IN HUBS

One target for this thesis work was to do the analyses of car hubs and implement changes if it's necessary.

In the next points, the thesis work tells about the modification conditions and proposes new design if no limitation given.

7.1 Proposed Changes with Limited Modification Conditions

The team want that the only change possible is modify the diameter of the principal hole in the middle of the hubs because the rest of parts have a specific design for adapt in the rest of the car and suspension.

Then if it is necessary, the only change is to do smaller holes.

This basic modification can do who the hubs endure all season.

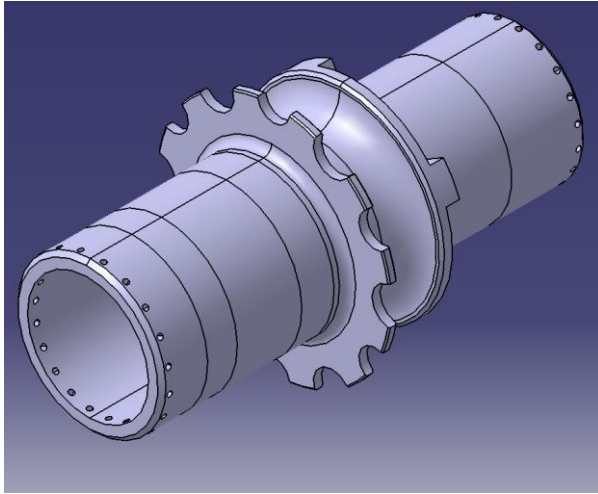
7.2 Proposed Changes without any Limited Modification Conditions

In case of a redesign without limited conditions, the best way is delete the small holes between bearings (there are in the piece because in this position we have a brake sensor) or change the position of it.

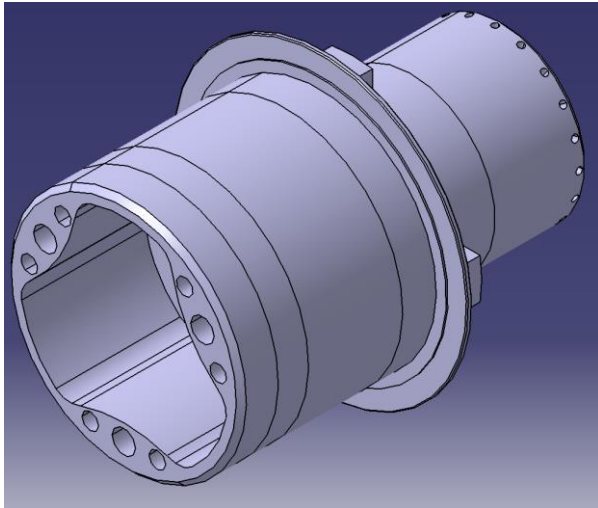
Also if is possible to do the part between bearings with the same diameter it can be better.

The reasons of these changes are because the holes and changes shapes are points that can increase the fatigue damage.

The next pictures show the possible changes (PICTURE 28 and 29):



PICTURE 28. Ideal Front Design. CATIA V5.



PICTURE 29. Ideal Rear Design. CATIA V5.

8 CONCLUSIONS AND MY COMMENTS

The objective of this thesis is to study the behavior of the axes of the wheels and make some possible recommendations for improving the performance of these as they will be used in the Formula Student car.

The preliminary studies and the studies conducted on the geometry have been especially necessary for the realization of these designs to provide to the Student Formula Team the best performance in the race.

Another essential task for the project has been the study of the different modeling and analysis programs used, without which would not have been possible to implement the project.

Finally, we have chosen to use the program CATIA and ANSYS program.

Because with ANSYS program, we can do more interesting study. We can obtain a better analysis with this program.

This study is the study by finite elements of the different pieces.

To get results and different simulations, first we conducted a study of the track and study of the forces that must endure each piece in each part of the circuit.

In the next step, these data have been entered in ANSYS with CAD models, allowing for a detailed finite element models analysis. This allowed study areas where stress concentration appeared and where they can begin to break our parts due to fatigue.

Finally, after the analysis in ANSYS, we have introduced some possible improvements or recommendations for future designs, where the optimal situation would be making real models of proposed modified axes in this project to really to see if its performance is higher than that obtained in analysis of original models.

With all this, we can conclude that it's a very rewarding project.

I learned to use common software's that are be used in the mechanical engineering companies.

Also I learned more about the fatigue design with cumulative damage, because in my home university, they didn't explain this theory.

Besides, with this project I learned how I can affront different problems that can appear during the development of a real project in a future work life.

This last point I think is the most important point of this rewarding project.

But the work doesn't ends here; I would like that next studies can complements the work presented here to achieve the best design, reliable and competent to participate in the Formula Student racing.

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APPENDICES

Appendix 1. Forces in One Lap

TIME (seconds)	FRONT (N)			REAR (N)			CURVE	from	to	Km/h
	Ka	Kd	Kt	Ka	Kd	Kt				
0	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
0,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
1	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
1,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
2	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
2,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
3	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
3,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
4	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
4,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	31	1	50
5,5	3296,077	2060,048	0,0001	3613,843	2258,652	0,0001	1			120
6	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	1	2	50
6,5	0,0001	1904,815	3175,279	0,0001	139,535	95,681	2			120
7	2158,544	1349,091	0,0001	2148,158	1342,599	0,0001	2			20
7,5	0,0001	91,603	181,058	0,0001	1250,483	1966,279	2			20
8	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
8,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
9	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
9,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
10	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
10,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
11	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
11,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
12	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	2	3	50
12,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	3			50
13	0,0001	100,289	111,826	0,0001	1369,061	2239,134	3			50
13,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	3	4	50
14	0,0001	1359,744	1921,039	0,0001	99,606	413,921	4			50
14,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	4			50
15	0,0001	100,289	111,826	0,0001	1369,061	2239,134	4			50
15,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	4	5	50
16	2788,611	1742,882	0,0001	2961,309	1850,818	0,0001	5			90
16,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	5	6	50
17	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	5	6	50
17,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	5	6	50
18	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	5	6	50
18,5	0,0001	1615,974	2510,639	0,0001	118,376	264,321	6			90
19	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	6			50
19,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	6			50
20	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	6	7	50

20,5	2788,611	1742,882	0,0001	2961,309	1850,818	0,0001	7		90
21	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	7 8	50
21,5	0,0001	1615,974	2510,639	0,0001	118,376	264,321	8		90
22	2158,544	1349,091	0,0001	2148,158	1342,599	0,0001	8		20
22,5	0,0001	91,603	181,058	0,0001	1250,483	1966,279	8		20
23	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	8 9	50
23,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	9		50
24	0,0001	100,289	111,826	0,0001	1369,061	2239,134	9		50
24,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	9 10	50
25	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	9 10	50
25,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	9 10	50
26	0,0001	1359,744	1921,039	0,0001	99,606	413,921	10		50
26,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	10		50
27	0,0001	100,289	111,826	0,0001	1369,061	2239,134	10		50
27,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	10 11	50
28	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	10 11	50
28,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	10 11	50
29	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	10 11	50
29,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	10 11	50
30	0,0001	1359,744	1921,039	0,0001	99,606	413,921	11		50
30,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	11		50
31	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	11 12	50
31,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	11 12	50
32	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	11 12	50
32,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	11 12	50
33	0,0001	1359,744	1921,039	0,0001	99,606	413,921	12		50
33,5	2158,544	1349,091	0,0001	2148,158	1342,599	0,0001	12		20
34	0,0001	91,603	181,058	0,0001	1250,483	1966,279	12		20
34,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	12 13	50
35	2788,611	1742,882	0,0001	2961,309	1850,818	0,0001	13		90
35,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	13 14	50
36	0,0001	1615,974	2510,639	0,0001	118,376	264,321	14		90
36,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	14		50
37	0,0001	100,289	111,826	0,0001	1369,061	2239,134	14		50
37,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	14 15	50
38	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	14 15	50
38,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	14 15	50
39	2788,611	1742,882	0,0001	2961,309	1850,818	0,0001	15		90
39,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	15 16	50
40	0,0001	1615,974	2510,639	0,0001	118,376	264,321	16		90
40,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	16		50
41	0,0001	100,289	111,826	0,0001	1369,061	2239,134	16		50
41,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	16 17	50
42	0,0001	1359,744	1921,039	0,0001	99,606	413,921	17		50
42,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	17		50
43	0,0001	100,289	111,826	0,0001	1369,061	2239,134	17		50
43,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	17 18	50
44	0,0001	1359,744	1921,039	0,0001	99,606	413,921	18		50

44,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	18		50
45	0,0001	100,289	111,826	0,0001	1369,061	2239,134	18		50
45,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	18 19	50
46	0,0001	1359,744	1921,039	0,0001	99,606	413,921	19		50
46,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	19		50
47	0,0001	100,289	111,826	0,0001	1369,061	2239,134	19		50
47,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	19 20	50
48	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	19 20	50
48,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	19 20	50
49	0,0001	1359,744	1921,039	0,0001	99,606	413,921	20		50
49,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	20		50
50	0,0001	100,289	111,826	0,0001	1369,061	2239,134	20		50
50,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
51	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
51,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
52	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
52,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
53	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	20 21	50
53,5	0,0001	1359,744	1921,039	0,0001	99,606	413,921	21		50
54	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	21		50
54,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	21		50
55	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	21 22	50
55,5	0,0001	1359,744	1921,039	0,0001	99,606	413,921	22		50
56	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	22		50
56,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	22		50
57	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	22 23	50
57,5	0,0001	1359,744	1921,039	0,0001	99,606	413,921	23		50
58	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	23		50
58,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	23		50
59	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	23 24	50
59,5	0,0001	1359,744	1921,039	0,0001	99,606	413,921	24		50
60	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	24		50
60,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	24		50
61	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	24 25	50
61,5	0,0001	1359,744	1921,039	0,0001	99,606	413,921	25		50
62	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	25		50
62,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	25 26	50
63	0,0001	1359,744	1921,039	0,0001	99,606	413,921	26		50
63,5	2158,544	1349,091	0,0001	2148,158	1342,599	0,0001	26		20
64	0,0001	91,603	181,058	0,0001	1250,483	1966,279	26		20
64,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	26 27	50
65	2788,611	1742,882	0,0001	2961,309	1850,818	0,0001	27		90
65,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	27 28	50
66	0,0001	1615,974	2510,639	0,0001	118,376	264,321	28		90
66,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	28		50
67	0,0001	100,289	111,826	0,0001	1369,061	2239,134	28		50
67,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	28 29	50
68	0,0001	1359,744	1921,039	0,0001	99,606	413,921	29		50

68,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	29		50
69	0,0001	100,289	111,826	0,0001	1369,061	2239,134	29		50
69,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	29 30	50
70	0,0001	1359,744	1921,039	0,0001	99,606	413,921	30		50
70,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	30		50
71	0,0001	100,289	111,826	0,0001	1369,061	2239,134	30		50
71,5	0,0001	100,289	111,826	0,0001	1369,061	2239,134	-	30 31	50
72	0,0001	1359,744	1921,039	0,0001	99,606	413,921	31		50
72,5	2336,052	1460,033	0,0001	2349,868	1468,667	0,0001	31		50
73	0,0001	100,289	111,826	0,0001	1369,061	2239,134	31		50

Appendix 2. Miner's Rule Front Hub

TIME	FRONT			cycles/laps		cycles	1/laps	%
	Ka	Kd	Kt	Km/h	n	Life Minimum (N)	D_i=(n/N)	
0	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
0,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
1	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
1,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
2	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
2,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
3	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
3,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
4	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
4,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
5,5	3296,077	2060,048	0,0001	120	6772,721088	1156555,726	0,00585594	0,59
6	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
6,5	0,0001	1904,815	3175,279	120	6772,721088	382299,037	0,017715768	1,77
7	2158,544	1349,091	0,0001	20	27090,88435	76946615,89	0,000352074	0,04
7,5	0,0001	91,603	181,058	20	27090,88435	100000000	0,000270909	0,03
8	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
8,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
9	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
9,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
10	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
10,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
11	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
11,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
12	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
12,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
13	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
13,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
14	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
14,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
15	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
15,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
16	2788,611	1742,882	0,0001	90	33863,60544	4969251,038	0,00681463	0,68
16,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
17	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
17,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
18	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
18,5	0,0001	1615,974	2510,639	90	33863,60544	1993195,113	0,016989609	1,70
19	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
19,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
20	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
20,5	2788,611	1742,882	0,0001	90	33863,60544	4969251,038	0,00681463	0,68
21	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
21,5	0,0001	1615,974	2510,639	90	33863,60544	1993195,113	0,016989609	1,70

22	2158,544	1349,091	0,0001	20	27090,88435	76946615,89	0,000352074	0,04
22,5	0,0001	91,603	181,058	20	27090,88435	100000000	0,000270909	0,03
23	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
23,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
24	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
24,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
25	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
25,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
26	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
26,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
27	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
27,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
28	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
28,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
29	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
29,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
30	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
30,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
31	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
31,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
32	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
32,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
33	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
33,5	2158,544	1349,091	0,0001	20	27090,88435	76946615,89	0,000352074	0,04
34	0,0001	91,603	181,058	20	27090,88435	100000000	0,000270909	0,03
34,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
35	2788,611	1742,882	0,0001	90	33863,60544	4969251,038	0,00681463	0,68
35,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
36	0,0001	1615,974	2510,639	90	33863,60544	1993195,113	0,016989609	1,70
36,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
37	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
37,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
38	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
38,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
39	2788,611	1742,882	0,0001	90	33863,60544	4969251,038	0,00681463	0,68
39,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
40	0,0001	1615,974	2510,639	90	33863,60544	1993195,113	0,016989609	1,70
40,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
41	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
41,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
42	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
42,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
43	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
43,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
44	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
44,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
45	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
45,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43

46	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
46,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
47	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
47,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
48	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
48,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
49	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
49,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
50	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
50,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
51	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
51,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
52	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
52,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
53	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
53,5	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
54	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
54,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
55	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
55,5	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
56	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
56,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
57	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
57,5	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
58	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
58,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
59	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
59,5	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
60	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
60,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
61	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
61,5	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
62	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
62,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
63	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
63,5	2158,544	1349,091	0,0001	20	27090,88435	76946615,89	0,000352074	0,04
64	0,0001	91,603	181,058	20	27090,88435	100000000	0,000270909	0,03
64,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
65	2788,611	1742,882	0,0001	90	33863,60544	4969251,038	0,00681463	0,68
65,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
66	0,0001	1615,974	2510,639	90	33863,60544	1993195,113	0,016989609	1,70
66,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
67	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
67,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
68	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
68,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
69	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
69,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43

70	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
70,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
71	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
71,5	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43
72	0,0001	1359,744	1921,039	50	430067,7891	39788197,42	0,010808929	1,08
72,5	2336,052	1460,033	0,0001	50	430067,7891	38313015,86	0,011225109	1,12
73	0,0001	100,289	111,826	50	430067,7891	100000000	0,004300678	0,43

Appendix 3. Miner's Rule Front Hub, Infinite Life = 0.

TIME	FRONT			cycles/laps		cycles	1/laps	%
	Ka	Kd	Kt	Km/h	n	Life Minimum (N)	D _i =(n/N)	
0	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
0,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
1	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
1,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
2	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
2,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
3	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
3,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
4	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
4,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
5,5	3296,077	2060,048	0,0001	120	6772,721	1156555,726	0,00585594	0,59
6	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
6,5	0,0001	1904,815	3175,279	120	6772,721	382299,037	0,017715768	1,77
7	2158,544	1349,091	0,0001	20	27090,88	76946615,89	0,000352074	0,04
7,5	0,0001	91,603	181,058	20	27090,88	100000000	0	0,00
8	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
8,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
9	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
9,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
10	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
10,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
11	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
11,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
12	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
12,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
13	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
13,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
14	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
14,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
15	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
15,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
16	2788,611	1742,882	0,0001	90	33863,61	4969251,038	0,00681463	0,68
16,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
17	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
17,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
18	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
18,5	0,0001	1615,974	2510,639	90	33863,61	1993195,113	0,016989609	1,70
19	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
19,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
20	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
20,5	2788,611	1742,882	0,0001	90	33863,61	4969251,038	0,00681463	0,68
21	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
21,5	0,0001	1615,974	2510,639	90	33863,61	1993195,113	0,016989609	1,70

22	2158,544	1349,091	0,0001	20	27090,88	76946615,89	0,000352074	0,04
22,5	0,0001	91,603	181,058	20	27090,88	100000000	0	0,00
23	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
23,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
24	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
24,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
25	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
25,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
26	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
26,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
27	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
27,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
28	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
28,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
29	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
29,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
30	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
30,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
31	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
31,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
32	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
32,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
33	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
33,5	2158,544	1349,091	0,0001	20	27090,88	76946615,89	0,000352074	0,04
34	0,0001	91,603	181,058	20	27090,88	100000000	0	0,00
34,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
35	2788,611	1742,882	0,0001	90	33863,61	4969251,038	0,00681463	0,68
35,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
36	0,0001	1615,974	2510,639	90	33863,61	1993195,113	0,016989609	1,70
36,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
37	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
37,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
38	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
38,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
39	2788,611	1742,882	0,0001	90	33863,61	4969251,038	0,00681463	0,68
39,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
40	0,0001	1615,974	2510,639	90	33863,61	1993195,113	0,016989609	1,70
40,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
41	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
41,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
42	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
42,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
43	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
43,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
44	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
44,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
45	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
45,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00

46	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
46,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
47	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
47,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
48	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
48,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
49	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
49,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
50	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
50,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
51	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
51,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
52	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
52,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
53	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
53,5	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
54	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
54,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
55	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
55,5	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
56	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
56,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
57	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
57,5	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
58	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
58,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
59	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
59,5	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
60	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
60,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
61	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
61,5	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
62	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
62,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
63	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
63,5	2158,544	1349,091	0,0001	20	27090,88	76946615,89	0,000352074	0,04
64	0,0001	91,603	181,058	20	27090,88	100000000	0	0,00
64,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
65	2788,611	1742,882	0,0001	90	33863,61	4969251,038	0,00681463	0,68
65,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
66	0,0001	1615,974	2510,639	90	33863,61	1993195,113	0,016989609	1,70
66,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
67	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
67,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
68	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
68,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
69	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
69,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00

70	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
70,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
71	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
71,5	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00
72	0,0001	1359,744	1921,039	50	430067,8	39788197,42	0,010808929	1,08
72,5	2336,052	1460,033	0,0001	50	430067,8	38313015,86	0,011225109	1,12
73	0,0001	100,289	111,826	50	430067,8	100000000	0	0,00

Appendix 4. Miner's Rule Rear Hub.

TIME	REAR			cycles/laps		cycles	1/laps	
	Ka	Kd	Kt	Km/h	n	Life Minimum (N)	D_i=(n/N)	
0	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
0,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
1	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
1,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
2	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
2,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
3	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
3,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
4	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
4,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
5,5	3613,843	2258,652	0,0001	120	6772,721088	9783,783787	0,692239448	69,22
6	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
6,5	0,0001	139,535	95,681	120	6772,721088	100000000	6,77272E-05	0,01
7	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
7,5	0,0001	1250,483	1966,279	20	27090,88435	22514562,58	0,001203261	0,12
8	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
8,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
9	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
9,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
10	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
10,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
11	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
11,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
12	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
12,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
13	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
13,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
14	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
14,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7076	0,944117248	94,41
15	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
15,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
16	2961,309	1850,818	0,0001	90	33863,60544	74205,65202	0,456348061	45,63
16,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
17	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
17,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
18	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
18,5	0,0001	118,376	264,321	90	33863,60544	100000000	0,000338636	0,03
19	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
19,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
20	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
20,5	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
21	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
21,5	0,0001	118,376	264,321	90	33863,60544	100000000	0,000338636	0,03

22	2148,158	1342,599	0,0001	20	27090,88435	873070,9145	0,03102942	3,10
22,5	0,0001	1250,483	1966,279	20	27090,88435	22514563,34	0,00120326	0,12
23	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
23,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
24	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
24,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
25	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
25,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
26	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
26,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
27	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
27,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
28	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
28,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
29	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
29,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
30	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
30,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
31	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
31,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
32	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
32,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
33	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
33,5	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
34	0,0001	1250,483	1966,279	20	27090,88435	22514560,65	0,001203261	0,12
34,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
35	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
35,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
36	0,0001	118,376	264,321	90	33863,60544	100000000	0,000338636	0,03
36,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
37	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
37,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
38	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
38,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
39	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
39,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
40	0,0001	118,376	264,321	90	33863,60544	100000000	0,000338636	0,03
40,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
41	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
41,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
42	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
42,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7103	0,944117242	94,41
43	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
43,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
44	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
44,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
45	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
45,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77

46	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
46,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
47	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
47,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
48	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
48,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
49	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
49,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
50	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
50,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
51	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
51,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
52	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
52,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
53	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
53,5	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
54	2349,868	1468,667	0,0001	50	430067,7891	455523,6699	0,944117326	94,41
54,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
55	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
55,5	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
56	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
56,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
57	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
57,5	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
58	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
58,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
59	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
59,5	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
60	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
60,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
61	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
61,5	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
62	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
62,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
63	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
63,5	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
64	0,0001	1250,483	1966,279	20	27090,88435	22514561,27	0,001203261	0,12
64,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
65	2961,309	1850,818	0,0001	90	33863,60544	74205,65198	0,456348062	45,63
65,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
66	0,0001	118,376	264,321	90	33863,60544	100000000	0,000338636	0,03
66,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6735	0,944117318	94,41
67	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
67,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
68	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
68,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
69	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
69,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77

70	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
70,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7103	0,944117242	94,41
71	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
71,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
72	0,0001	99,606	413,921	50	430067,7891	100000000	0,004300678	0,43
72,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
73	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77

Appendix 5. Miner's Rule Rear Hub, Infinite Life = 0.

TIME	REAR			cycles/laps		cycles	1/laps	
	Ka	Kd	Kt	Km/h	n	Life Minimum (N)	D _i =(n/N)	
0	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
0,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
1	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
1,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
2	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
2,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
3	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
3,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
4	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
4,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
5,5	3613,843	2258,652	0,0001	120	6772,721088	9783,783787	0,692239448	69,22
6	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
6,5	0,0001	139,535	95,681	120	6772,721088	100000000	0	0,00
7	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
7,5	0,0001	1250,483	1966,279	20	27090,88435	22514562,58	0,001203261	0,12
8	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
8,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
9	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
9,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
10	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
10,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
11	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
11,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
12	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
12,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
13	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
13,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
14	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
14,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7076	0,944117248	94,41
15	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
15,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
16	2961,309	1850,818	0,0001	90	33863,60544	74205,65202	0,456348061	45,63
16,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
17	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
17,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
18	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
18,5	0,0001	118,376	264,321	90	33863,60544	100000000	0	0,00
19	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
19,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
20	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
20,5	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
21	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
21,5	0,0001	118,376	264,321	90	33863,60544	100000000	0	0,00

22	2148,158	1342,599	0,0001	20	27090,88435	873070,9145	0,03102942	3,10
22,5	0,0001	1250,483	1966,279	20	27090,88435	22514563,34	0,00120326	0,12
23	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
23,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
24	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
24,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
25	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
25,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
26	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
26,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
27	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
27,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
28	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
28,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
29	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
29,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
30	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
30,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
31	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
31,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
32	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
32,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
33	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
33,5	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
34	0,0001	1250,483	1966,279	20	27090,88435	22514560,65	0,001203261	0,12
34,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
35	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
35,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
36	0,0001	118,376	264,321	90	33863,60544	100000000	0	0,00
36,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
37	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
37,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
38	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
38,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
39	2961,309	1850,818	0,0001	90	33863,60544	74205,65149	0,456348065	45,63
39,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
40	0,0001	118,376	264,321	90	33863,60544	100000000	0	0,00
40,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
41	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
41,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
42	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
42,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7103	0,944117242	94,41
43	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
43,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
44	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
44,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
45	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
45,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77

46	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
46,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
47	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
47,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
48	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
48,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
49	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
49,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
50	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
50,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
51	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
51,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
52	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
52,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
53	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
53,5	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
54	2349,868	1468,667	0,0001	50	430067,7891	455523,6699	0,944117326	94,41
54,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
55	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
55,5	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
56	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
56,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
57	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
57,5	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
58	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
58,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
59	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
59,5	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
60	2349,868	1468,667	0,0001	50	430067,7891	455523,6701	0,944117326	94,41
60,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
61	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
61,5	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
62	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
62,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
63	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
63,5	2148,158	1342,599	0,0001	20	27090,88435	873070,9173	0,03102942	3,10
64	0,0001	1250,483	1966,279	20	27090,88435	22514561,27	0,001203261	0,12
64,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
65	2961,309	1850,818	0,0001	90	33863,60544	74205,65198	0,456348062	45,63
65,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
66	0,0001	118,376	264,321	90	33863,60544	100000000	0	0,00
66,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6735	0,944117318	94,41
67	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
67,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
68	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
68,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
69	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
69,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77

70	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
70,5	2349,868	1468,667	0,0001	50	430067,7891	455523,7103	0,944117242	94,41
71	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
71,5	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77
72	0,0001	99,606	413,921	50	430067,7891	100000000	0	0,00
72,5	2349,868	1468,667	0,0001	50	430067,7891	455523,6734	0,944117319	94,41
73	0,0001	1369,061	2239,134	50	430067,7891	4903149,758	0,087712554	8,77